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GEOLOGY AND ORE DEPOSITS

OF THE

TINTIC MINING DISTRICT, UTAH

BY

WALDEMAR LINDGREN AND G. F. LOUGHLIN

WITH A HISTORICAL REVIEW

BY

V. C. HEIKES

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GEOLOGY AND ORE DEPOSITS OF THE TINTIC MINING DISTRICT, UTAH.

By Waldemar Lindgren and G. F. Loughlin.

INTRODUCTION.

Tintic, Park City, and Bingham have always been the three great silver-lead producing districts of Utah. Of late years Bingham has also become one of the most prominent copper districts of the world, and Tintic has likewise entered the ranks of the great copper camps.

The Tintic district, named after a noted Indian chief of the Ute tribe, is about 60 miles south of Salt Lake City, in the East Tintic Mountains, the most easterly of the Basin Ranges. This range forms the southward continuation of the metal-rich Oquirrh Range and lies only 20 miles west of the mighty Wasatch uplift. From 1869 to the end of 1916, according to statistics compiled by V. C. Heikes,[1] metals have been produced in this district to the gross value of $169,326,248. Tintic is a district of complex ores yielding, in order of value, silver, gold, lead, copper, and zinc, besides which some bismuth, arsenic, and antimony are recovered. The annual production, though uneven, had risen to a maximum of nearly $10,000,000 in 1912.

A careful geologic examination of the three districts named above was planned at an early date by the United States Geological Survey and carried out under the direction of S. F. Emmons. The Tintic report[2] was published in 1898, the field work having been completed in 1897. The stratigraphic and economic studies were undertaken by G. W. Tower, and the igneous rocks were investigated by George Otis Smith. The results were also summarized in Folio 65 of the Geologic Atlas of the United States, by Tower, Smith, and Emmons. This folio contained a map of an area of 12 square miles, which includes the principal mines of the district, on the scale of 1:9,600, and a map of a larger area (now called the Tintic quadrangle), including the central part of the East Tintic Mountains, on the scale of 1:62,500, or about 1 mile to the inch. These maps have been revised and reproduced as Plates IV and I, respectively, of the present report.

Since the first report was published the annual production of the district has about doubled, the development work, both laterally and in depth, has increased enormously, and an entirely new line of ore deposits on the east side of the district has been opened. The Director of the Survey therefore decided that a review of the new developments would be desirable. The resurvey was assigned in 1911 to the present authors; the examination of the structural, stratigraphic, and igneous geologic features was undertaken by G. F. Loughlin and the investigation of the ore deposits by Waldemar Lindgren, who also had general supervision of the work.

The field examination was made in the last two summer months of 1911, and the district was revisited for a short time by Mr. Loughlin in 1913 and by both authors in 1914. Mr. Loughlin also assisted in the examination of some of the mines and studied the oxidized zinc ores.

The resurvey was confined chiefly to the area of the mining district proper (Pl. IV, in pocket). Work beyond this area was limited to outlying mining districts and points of special geologic interest.

A more detailed study has resulted in considerable revision of the mapping of the sedi-

[1] U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 402, 1916.

[2] Tower, G. W., jr., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, pp. 601-767, 1898.

mentary area, based on the discovery of new fossil localities by F. B. Weeks [1] and G. F. Loughlin. The fault systems have also been worked out more fully. Revision of the geology of the igneous rocks has consisted chiefly in more detailed mapping and description.

The mine owners of the district have aided the resurvey by the most cordial cooperation. With two exceptions, fortunately of minor importance, all facilities for underground work, mine maps, and assistance of various kinds were cheerfully furnished.

Special thanks are due to the gentlemen in charge of the Knight properties, particularly to Messrs. Jesse Knight and L. E. Riter. Mr. Milan L. Crandall, jr., engineer for these properties, spared no time or effort in furnishing data, and several of the most important sections of underground workings used in this report are copies of his careful and exact surveys.

Cordial thanks are also due to Messrs. Jackson McChrystal, J. H. McChrystal, G. W. Riter, C. C. Griggs, C. E. Allen, and Fewson Smith for many courtesies.

The office work on data and specimens has consumed much time. The new methods of metallographic research have been applied to the study of the ores, and in this work the senior author has received much aid from Messrs. W. L. Whitehead and A. H. Means, of the Massachusetts Institute of Technology. All the economic work has been done in the geologic laboratory of this institute. Messrs. Means and Whitehead have especially assisted in the examination of polished sections and have made most of the excellent photographs of such specimens here reproduced. They have also done special work on the mineralogy of the district. The fossils collected have been examined by Messrs. G. H. Girty and Edwin Kirk, of the United States Geological Survey. Many chemical analyses of ores have been made by Mr. R. C. Wells, also of the Geological Survey, whose work and suggestions have been greatly appreciated. Several minerals have been determined by Mr. W. T. Schaller, of the same organization.

Since the manuscript of this report was transmitted for publication a paper on the Tintic district by Crane [2] has been published. This paper differs from the present report in the necessarily arbitrary subdivision of the sedimentary formations and in the interpretation of certain features of stratigraphy, structure, and geology of the igneous rocks. It considers only the more general features of the ore deposits, regarding which it accords with the present report.

NOTE.—Further comments on this resurvey of the Tintic mining district can appropriately be added by one of the geologists making the earlier survey. Comparison of the later mapping with the earlier brings out differences that are in part explained by the much extended mine development and the later discovery of fossil localities but that are also due to more thorough field work. Comparison of the workers engaged in the two investigations of this area need not be made, but it is of value to compare methods and standards of work. The 14 years between 1897 and 1911 were years of progress in geologic science, and though no great changes in theory or notable discoveries were made there was a steady improvement in method. Some field workers adopted refinements in mapping earlier than others; the desire for quantitative results was stronger with certain of the earlier geologists like Mr. Gilbert than with other geologists, even of a later day; but on the whole there is apparent a steady trend toward exactness in map delineation and quantitative accuracy in results. New methods are being adopted in both field and laboratory, all to the end of making the work more useful. With this view of the raising of standards it is gratifying to compare the resurvey with the earlier work. It is believed that the geologists responsible for the original survey would have done better work in 1911 than they did in 1897 and that probably the authors of the present report would have been less successful in 1897 than they have been in this piece of thorough research.—G. O. S.

[1] Data incorporated by C. D. Walcott, Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 156, 157, 196, 197, 1912.

[2] Crane, G. W., Geology of the ore deposits of the Tintic mining district: Am. Inst. Min. Eng. Trans., vol. 54, pp. 342-355, 1917.

PART I. GENERAL GEOGRAPHY AND GEOLOGY.

By G. F. LOUGHLIN.

GEOGRAPHIC POSITION.

The East Tintic Mountains form one of the Basin Ranges of Utah and have the north-south trend characteristic of these ranges. (See fig. 1.) They lie just west of the 112th meridian of longitude and are crossed by the 40th parallel of latitude. They are thus only 10 to 20 miles distant from the south end of the Wasatch Mountains and form the easternmost of the Basin Ranges in this latitude. In total length the East Tintic Mountains do not exceed 40 miles, but they may be considered as continued to the north in the Oquirrh Mountains and to the south in the Canyon Range. Both of these lie slightly farther west than the East Tintic Range but are separated from it by only narrow passes. They are from 5 to 10 miles wide.

The Tintic mining district is on the eastern (near the crest) and western slopes of the central portion of the East Tintic Mountains and includes portions of Juab and Utah counties. A few small producing mines lie beyond the limits of this area. The district is about 60 miles south of Salt Lake City, with which it is connected by two railroads—the Los Angeles & Salt Lake and the Denver & Rio Grande. Eureka, Mammoth, Robinson (now included in Mammoth City), and Silver City are the principal towns and are situated in gulches or broad canyons of the western slope. The abandoned town of Diamond is similarly situated south of the active part of the district. Knightville, just west of the divide, is included within the limits of Eureka. Homansville,

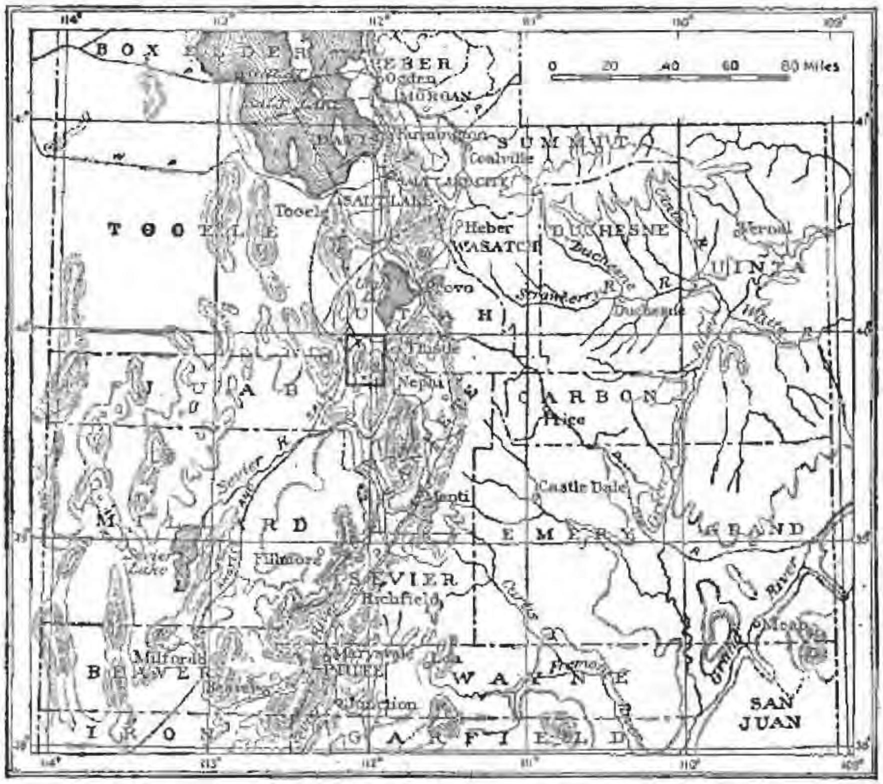


FIGURE 1.—Index map showing location of East Tintic Mountains and Tintic quadrangle (indicated by small rectangle).

where the first mill was erected but where only one or two houses now remain, is 1½ miles east of the divide and northeast of Eureka. To the west of the mountains is Tintic Junction, a section point on the Los Angeles & Salt Lake Railroad, where the Tintic branch leaves the main line, 3 miles southwest of Eureka. The old smelter town of Tintic, also important in the early days, was situated farther south, in the middle of Tintic Valley. To the east of the mountains, in Goshen Valley, are the farming towns of Elberta and Goshen, the latter just east of the Tintic quadrangle.

TOPOGRAPHY.

MOUNTAINS.

The East Tintic Mountains as a whole are rather complex and form parts of the extensive but now partly buried system of block mountains known as the Basin Ranges. They are connected with the West Tintic Mountains by a low east-west ridge, composed largely of gravels, which forms the divide between Tintic and Rush valleys; on the east they are connected at the head of Goshen Valley with Long Ridge, which extends southward and northeastward from that point and at its northeast end is connected with the Wasatch Mountains by the low hills south of Santaquin. The East Tintic Mountains are too maturely dissected to offer convincing evidence of block faulting, although their topography suggests that structure in a few places, especially at the head of Tintic Valley. Here the front of the range makes an abrupt turn westward, squarely across the strike of the rock formations, as if a large block west of the mining district had dropped below the present level of the valley. There is, however, structural evidence of faulting north of Silver Pass. (See p. 89.) Structural evidence of block faulting corresponding to minor ridges is also clearly exposed east of the quadrangle, at the northeast end of Long Ridge and in the adjoining part of the Wasatch Mountains.[1] The existence of these faults leaves little doubt that the East Tintic Mountains consist of a composite fault block, whose outlines and identity have been largely obscured by erosion. There is abundant evidence of faulting within the Tintic mining district, but all the notable faults there appear to be older than the elevation of the Basin Ranges.

The central part of the range, which includes the mining district, is a rather sinuous ridge interrupted by the Eureka-Homansville Pass and by Silver Pass, both of which lie along zones weakened by faulting—in the former pass prevolcanic and in the latter postvolcanic. The slopes of the ridge are cut by major and minor canyons and gulches, the largest of which merge into the wide valleys on the east and west. The relief is strongly marked, the crest attaining an altitude of 8,214 feet, whereas Tintic Valley, on the west, descends to an elevation of 5,600 feet and Goshen Valley, on the east, to 4,500 feet. The highest peak (see Pl. I) is Tintic Mountain, near the south end of the ridge. The other principal peaks are Buckhorn Mountain (7,852 feet), Sunrise Peak (7,693 feet), Mammoth Peak (8,104 feet), Sioux Peak (8,094 feet), Godiva Mountain (8,040 feet), Eureka Peak (7,909 feet), Packard Peak (7,828 feet), and Pinyon Peak (7,702 feet).

The character of the topography is well shown in Plates VI, VII, VIII, IX, and X, *A*. The highest peaks, nearly all on the backbone of the ridge, are characterized by a good number of outcrops, many of them cliffs, of which the Mammoth Bluffs, measuring 140 feet from top to bottom, are the highest. The branch spurs of the range as a rule have smoother surfaces, owing to the almost complete disintegration of their outcrops into talus. (See Pl. VI, *A*.) The branch ridge of limestone between Mammoth and Eureka is an exception to this rule, and contains Eureka Peak, one of the highest in the district. (See Pl. IX, *A*.) The topography south of Ruby Hollow (see Pl. I), where only volcanic rocks are exposed, is symmetrical, the crest of the range lying midway between the two principal valleys. Sunrise Peak, which is an exception to this rule, is a volcanic plug of monzonite porphyry and owes its relatively high altitude to the rapid erosion of the loosely textured tuffs that surround it. Treasure Hill (6,852 feet) owes its prominence to a local silicification of the rock. North of Ruby Hollow the crest of the range shifts westward, continuing along limestone peaks, and its position is evidently controlled by differences in the weather-resisting properties of the different rocks.

[1] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 448-451, 1913.

A. SUNRISE PEAK AND VOLCANO RIDGE, LOOKING SOUTH FROM TREASURE HILL.

B. PANORAMA OF EAST TINTIC MOUNTAINS, LOOKING NORTH FROM TREASURE HILL ACROSS RUBY HOLLOW.

A. PANORAMA OF MAMMOTH HILL AND SURROUNDING MOUNTAINS.

1, Opex property; 2, Emerald property; 3, Grand Central mine; 4, Mammoth mine; 5, Lower Mammoth mine; 6, Gold Chain mine; 7, Black Jack mine; 8, Black Jack open cut iron mine.

B. PANORAMA OF EUREKA AND VICINITY.

1, Bullion Beck mine; 2, Gemini mine; 3, Chief Consolidated mine; 4, Snow Flake mine; 5, Eureka Hill mine; 6, Tetro tunnel; 7, Godiva mine.

The limestone is distinctly the most resistant to weathering of all the rocks in the range under existing climatic conditions, owing to its generally massive character and freedom from excessive jointing. The quartzite, though harder and relatively insoluble, is split into thin slabs by numerous joints that greatly promote mechanical disintegration. Quartzite Ridge, just northwest of Robinson, is the highest part of the quartzite area, but it is only as high as the lowest limestone peak just east of it. Its prominence is in part due to rapid erosion of the narrow shale belt that borders it on the east. North of Eureka Gulch the quartzite is limited to the conical, débris-covered foothills, in strong contrast to the higher limestone hills on the east. (See Pl. VIII, *B*.) The position of the quartzite along the edge of the range may in part account for its more rapid denudation but does not explain its thorough disintegration into small, flat fragments.

The igneous rocks have undergone the most extensive erosion, as will be seen by a comparison of the west fronts of the range north and south of Mammoth Gulch and by a glance at Plates VI, IX, *B*, and X, *B*. Exposures of monzonite are mostly reduced to small rounded residual boulders; those of intrusive rhyolite porphyry to small angular fragments. The effusive rocks as a rule have disintegrated into angular fragments, or here and there into rounded boulders, except along the higher divides, where small to moderately large cliffs are common. (See Pl. VIII, *A*.) The contrast in weathering between the igneous rocks and limestones is shown southeast of Mammoth, where the low subdued hills of monzonite and related porphyry stop abruptly against the high, steep limestone slopes. (See Pl. VI, *B*.)

VALLEYS.

No special attention has been given to the large intermontane valleys bordering the range. They are typical of Great Basin valleys more or less filled with gently sloping alluvial deposits derived from the mountains. The central part of Goshen Valley is covered with silt and clay deposited in the ancient Lake Bonneville, of which the present Utah Lake is a remnant. These valleys represent the down-faulted portions of the Great Basin, but their original outlines are now obscured by their marginal alluvial slopes. They are becoming of increasing value as farm lands. The farms of Goshen and Elberta are irrigated by water from Currant (or Salt) Creek and a few farms at the mouth of Eureka Gulch have been irrigated by water pumped from the Centennial Eureka mine; but most of the farms in Tintic, Rush, and Cedar valleys are dry farms.

The lateral valleys in the sedimentary areas penetrate the range across the strike of the strata, but their branches conform with the strike. Faulting and shattering have taken place in both directions, and many of the valleys coincide with faults. Eureka Gulch is approximately parallel to a strong fault zone which was formed and evidently deeply eroded prior to volcanic eruption. (See Pl. V, section A–A′.) Its present unusual form, steep and narrow in its lower part and wide open in its upper part, is evidently due to the relatively rapid erosion of the volcanic rock (Packard rhyolite). It is separated by a low, flat divide from Homansville Canyon, which, owing to its steeper grade, appears to have undergone the more rapid erosion, as is indicated by a westward migration of the divide into the alluvium at the head of Eureka Gulch. Here the area of alluvium slopes gently westward, but its east end has been removed, and on the east side of the divide the underlying rhyolite ledges are exposed along the creek bed.

Mammoth Gulch also lies along the course of a strong prevolcanic east-west fault zone, and some of its north branches also follow prevolcanic north-south faults, but some of the strongest faults in the district show no relation to topography, probably because of their prevailing "tightness," which is described in the section on faulting (pp. 77–87). None of the valleys in the sedimentary area appear to mark the position of late faults developed by the Basin Range uplift. The lateral valleys in the igneous areas can not be definitely associated with faulting, because of the uniform character of the surrounding rock and its advanced stage of disintegration. The fact that they parallel the valleys in the sedimentary areas is not significant, as those valleys follow prevolcanic faults.

The lateral valleys, extending well back toward the crest of the range, have afforded

the best sites for mining towns. Eureka (Pl. VII, *B*) is the most favorably situated, the low divide and relatively gentle grades giving it direct connection by railroad with the country both east and west of the mountains. The low divide also, however, affords the principal path for the frequent windstorms that blow from Tintic Valley eastward. Mammoth Gulch is wider in proportion to its length, perhaps, owing to more rapid erosion in faulted and shattered ground, which gives it a basin-like character (Pl. VII, *A*), and is favored by its proximity to some of the most active mines in the district. The merging of its lower part with Tintic Valley is shown in Plate X, *A*. Silver City is situated at the mouth of Dragon Canyon, where it has railroad facilities and is within easy reach of the mines in the igneous area. Owing to the idleness of nearly all these mines and of the Tintic smelter, Silver City is not so flourishing now as formerly. The idleness of all the mines around Diamond accounts for its total abandonment, in spite of its good location.

DRAINAGE.

The area shown in Plate I (in pocket) is tributary to three drainage basins—Tintic Valley, which in turn is tributary to the Sevier Basin; Goshen Valley, which drains northward into Great Salt Lake; and Cedar Valley, an independent closed basin. No perennial streams rise in the East Tintic Mountains, but in spite of this fact their slopes have been well sculptured. Intermittent streams, which carry water only after cloudbursts, are the only existing agency to account for the sculpturing, but it is quite possible that much of the erosion was accomplished by former perennial mountain streams during the humid climate of Lake Bonneville time.

The nearest existing perennial stream is Currant Creek (also called Salt Creek), which rises east of Mount Nebo, at the south end of the Wasatch Range. This creek cuts through the northeastern portion of Long Ridge in a bold canyon, emerging into Goshen Valley and entering the Tintic quadrangle about 2 miles southeast of Elberta. It follows a winding course northward, leaving the quadrangle again due east of Elberta and finally reaching Utah Lake. Currant Creek furnishes the water used for irrigation in the towns of Elberta and Goshen.

WATER SUPPLY.

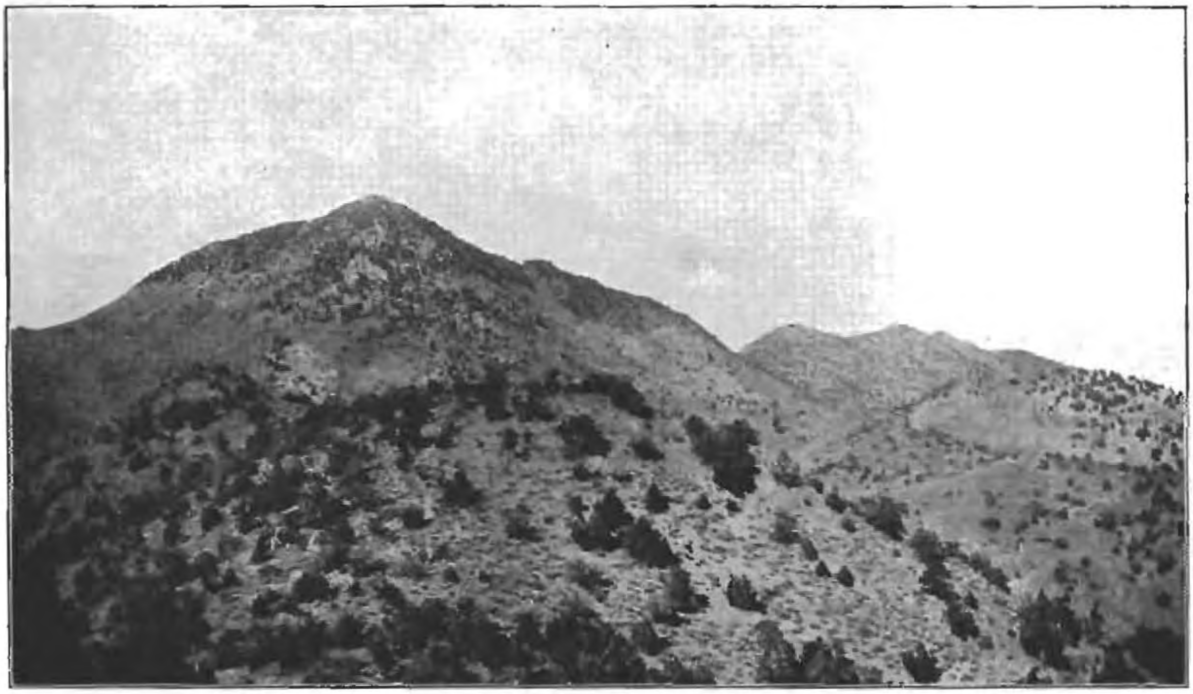
SPRINGS AND WELLS.[1]

There are several springs scattered over the east slope of the range as far south as Diamond and on both sides from Diamond southward, but their run-off travels only a short distance (100 feet to a mile or more) before it is absorbed by the soil. These springs occur in or near volcanic rock. The rock itself is nearly impervious, but its upper portion has been largely disintegrated into loose, porous materials which form a considerable surface covering in places that are protected from active erosion. Rain water accumulates in débris-filled depressions or seeps along gentle slopes upon the underlying impervious fresh rock, to emerge as a spring where the rock crops out. The springs are small, and their flow varies directly with the rainfall. Silver City is supplied with water from a group of these springs.

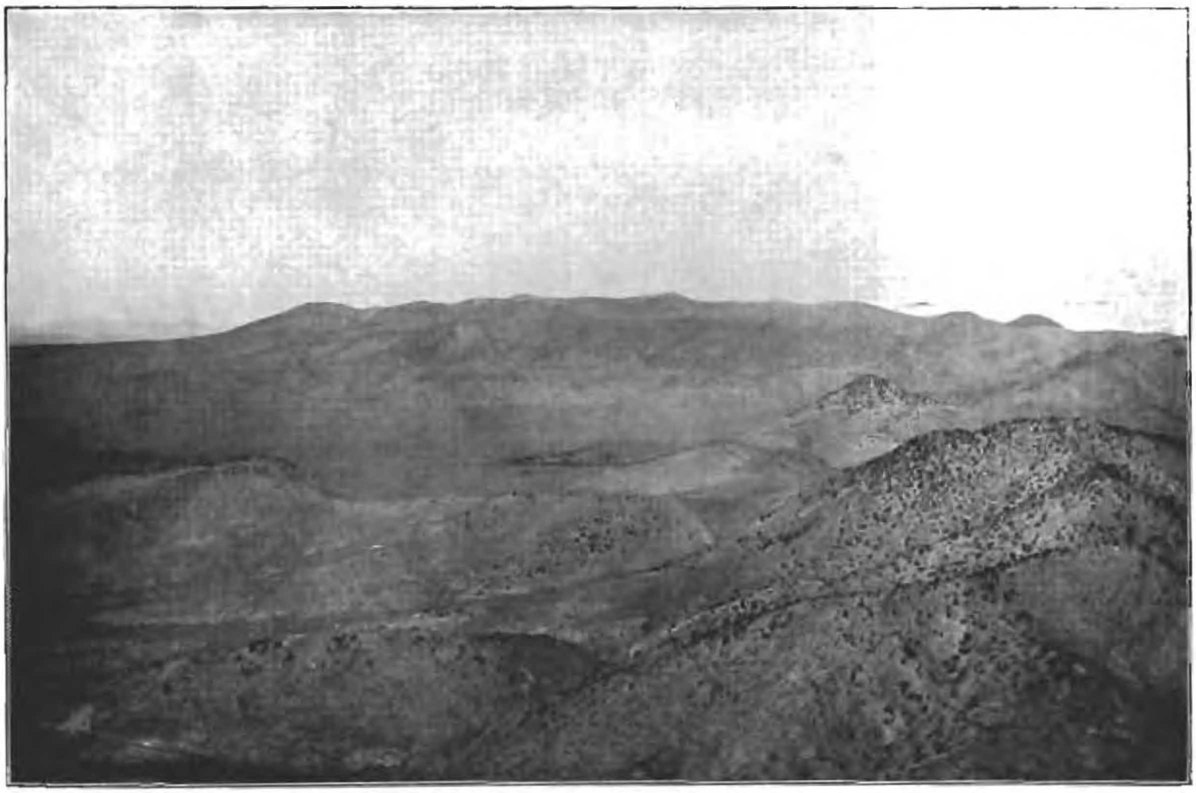
The water supplies of Eureka, the Denver & Rio Grande Railroad, and several mines are obtained from wells and infiltration galleries driven in the surface débris over the rhyolite and in the upper decomposed portion of the rhyolite itself. The wells are distributed from Eureka to Homansville. Private wells in Eureka range from 15 to 125 feet in depth, and such wells, especially the more western, are in danger of contamination from the city's drainage. Shafts and tunnels vary in depth and length. The Eureka Hill pumping plant, in the Homansville Basin, which supplies water for the city of Eureka, is the most extensive, having a main shaft 265 feet deep, two minor shafts, and tunnels said to aggregate several thousand feet in length. Its pump is operated at the rate of 80 gallons a minute for 5 to 12 hours each day, fully 50,000 gallons being withdrawn on certain days. The normal water level is reported to be 20 feet below the surface, but the level is easily lowered by pumping or by unusually dry seasons.

The water supply of Mammoth and Robinson is obtained 18 miles to the west, from Cherry Creek, on the west slope of the West Tintic Mountains. The water is pumped over the

[1] Largely abstracted from Meinzer, O. E., Ground water in Juab, Millard, and Iron counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, pp. 81–86, 1911.



A. PACKARD PEAK.



B. FOOTHILLS NORTHWEST OF EUREKA AND HEAD OF TINTIC VALLEY.

A. EUREKA PEAK FROM WEST SLOPE OF GODIVA MOUNTAIN.

B. RHYOLITE HILLS EAST OF GODIVA MOUNTAIN, FROM SIOUX PEAK.

The highest cone-shaped hill, according to Plate I, has an elevation of 7,007 feet.

crest of the ridge and piped across Tintic Valley to Robinson, where it is again pumped to the mines and dwellings of Mammoth.

GROUND WATER IN MINES.

Mines in the igneous rocks have struck ground-water level at depths of a few hundred feet. At the time of the earlier survey (1896) permanent water had been struck in the monzonitic rocks at depths ranging from little more than 100 feet to over 650 feet. At the Joe Bowers No. 2 mine, on the northeast slope of Treasure Hill, water was struck 175 feet below the surface (over 6,500 feet above sea level); in the Homestake, on the south slope of Treasure Hill, 200 feet down (6,320 feet or more above sea level); in the Sunbeam at the 490-foot level (altitude, 6,040 feet) in sufficient quantity to prevent profitable mining at greater depths. In the Iron Duke a continuous flow was met a short distance below the 100-foot level (altitude about 6,190 feet), and at the 350-foot level (altitude, 5,940 feet) water was pumped at the rate of 4,000 gallons a day. In the Swansea water was found just below the 650-foot level (altitude about 5,530 feet). These depths (except the first two) are plotted in figure 2, which also includes the southward projection of the shaft of the Dragon iron mine. The data are too meager to give a good idea of the relations between surface and ground water. The shallow depth in the Iron Duke shaft, which appears abnormal, may be due to its location at the southeast base of a high hill, nearly in the bed of the creek that drains all the monzonite area to the north and east. The difference in depth in the Swansea and Sunbeam mines agrees well with the general slope of the surface. The shaft of the Dragon iron mine furnishes a striking contrast. Although driven in higher ground and reaching a greater depth (1,025 feet) than the Sunbeam shaft, its bottom is dry. A vertical drill hole extending 800 feet below its bottom is also dry. The shaft and all but the lowest 4 feet of the drill hole are in metamorphic limestone near the monzonite contact. Water has been struck on the 800 and 1,000 foot levels of the Dragon iron mine, south and southeast of the shaft, but this comes from fissures and the rest of these levels is practically dry. The ground-water surface in the limestone, as shown in the next paragraph, is very low, and if fissures are present in the overlying porphyry to conduct the water down into the limestone, there may be a tendency for ground water to flow downward toward and into the limestone and for the ground-water surface to follow a steep slope of unknown depth from one rock formation into the other. In figure 2 the normal ground-water surface in the monzonite and porphyry is shown by the horizontal long-dash line and the sloping surface toward the Dragon shaft by the dotted line.

In the mines in limestone local watercourses, due to some impervious bed or dike, have been found at rather shallow depths. For example, in the May Day mine a watercourse was tapped along the contact of a decomposing porphyry dike which has been cut at certain places between the 200 and 500 foot levels, but the lowest workings, including the 1,100-foot level, are dry. In the Northern Spy a watercourse was struck between the 800 and 900 foot levels, and water now stands knee-deep on the 900-foot level (6,630 feet above the sea), below which no work has been done. The geologic map (Pl. IV) shows the proximity of the workings to a small monzonite stock, which may account for the local abnormally high water level. In the Yankee mine a watercourse is tapped at the 1,300-foot level, where the shaft passes through the upper contact of a black shaly bed; but the water is piped for 700 feet down and disappears through fractures at the bottom of the 2,000-foot shaft (5,080 feet above sea level and 580 feet above the flat around Utah Lake).

The great depth of the permanent water level is shown by the depths at which water stands in the only deep mines that have reached water level: Gemini, at the 1,650-foot level (altitude 4,813 feet); Centennial Eureka, at a depth of 2,036 feet (altitude about 4,851 feet); Opex, at a depth of 2,170 feet (altitude 4,791 feet); Grand Central, at a depth of 2,390 feet (altitude 4,759 feet); Chief Consolidated, at a depth of 1,815 feet (altitude 4,755 feet). The Mammoth mine, 2,362 feet deep (altitude 4,690 feet), has not reached permanent water level.

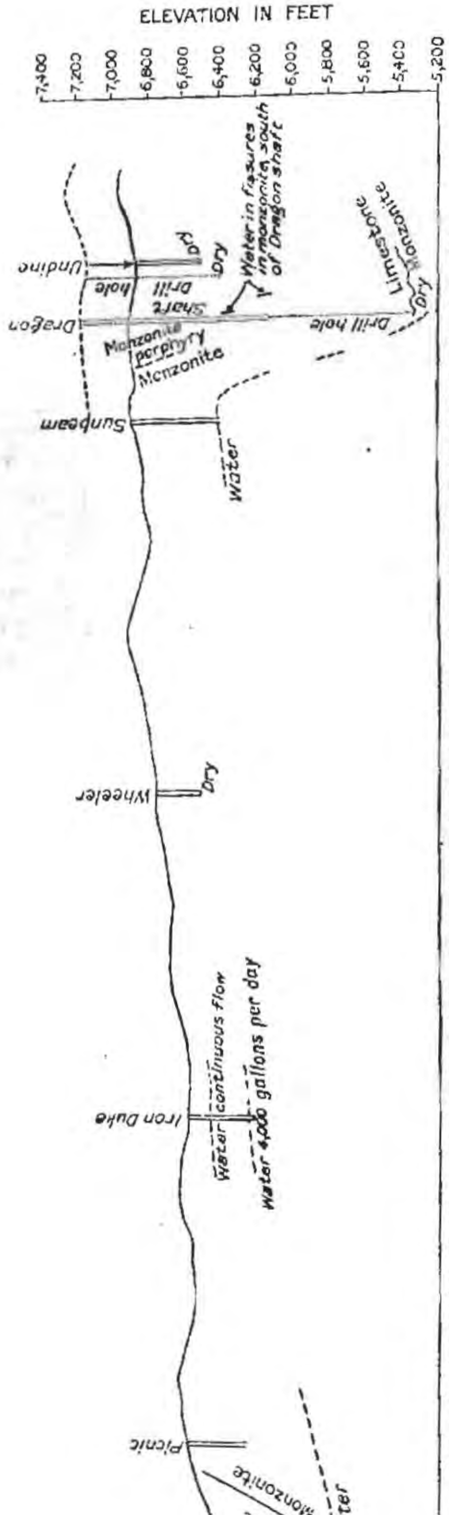


FIGURE 2.—Section through Swansea and Sunbeam shafts, showing known elevations of ground-water surface in the monzonite and adjacent porphyry.

In the East Tintic district[1] the Tintic Standard shaft has passed through 700 feet of limestone and a little shale and gone 300 feet into the underlying quartzite (altitude about 5,000 feet, or 500 feet above Utah Lake) without striking water. Some seepages have been opened by drifts along the contact of quartzite and shale on the 1,000-foot level and along an inclined winze that follows the contact down to and below the 1,300-foot level, but no pumping is necessary. This is interesting in view of the fact that in some of the ranges west of the East Tintic Mountains springs are found in quartzite areas, and shallow prospects in those areas have struck water. The known occurrences of ground water in the limestone and its relations to the topography and to the level of Utah Lake are shown in figure 3.

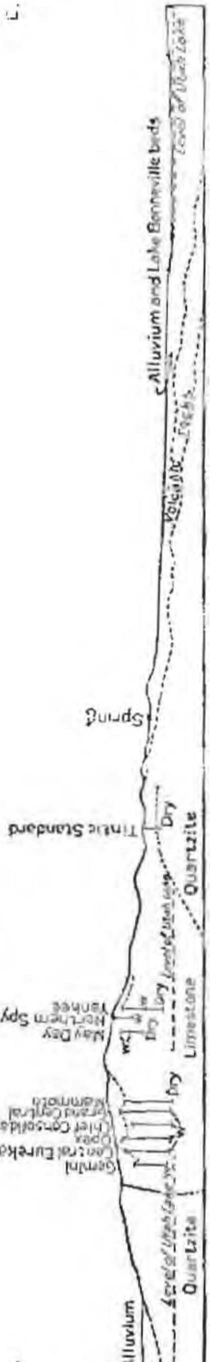


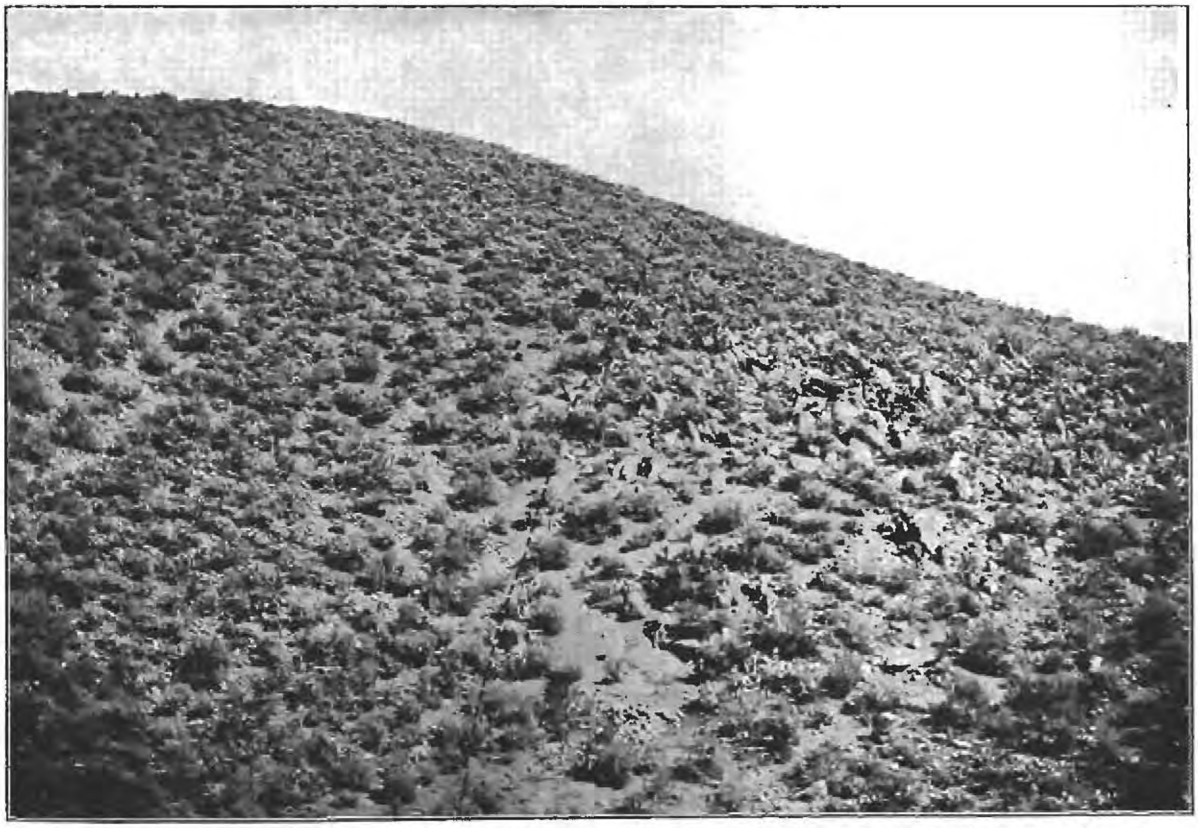
FIGURE 3.—Generalized section along line B–B, Plate IV, showing depth of ground water (W) in the limestone and the level of Utah Lake.

VEGETATION.

The East Tintic Mountains have the scanty vegetation of an arid region. In general the landscape presents the somber dull-gray and brown tints of rock masses and débris more or less obscured by low sagebrush. Only rarely is the monotony varied by the green of a tree-covered slope or ravine.

[1] The name "East Tintic district" is used to designate the area in the Tintic quadrangle east of meridian 112° 5′ and south of the Denver & Rio Grande Railroad.

A. MOUTH OF MAMMOTH GULCH AND TINTIC VALLEY, FROM LOW SPUR SOUTH OF HERKIMER SHAFT.



B. CONTACT OF QUARTZ PORPHYRY AND MONZONITE SOUTHEAST OF ROBINSON.

On the highest peaks and exposed rocky points occur different species of cactus, the most common of which are the prickly pears *Opuntia* and *Echinocactus*. The more common trees of the higher slopes are the piñon (*Pinus monophylla*), the mountain mahogany (*Cercocarpus ledifolius*), and the juniper, locally called cedar (*Juniperus utahensis*). Lower, in the dry ravines, are thickets of scrubby maple, especially on the eastern slope, and the aspens are found in sheltered spots, more commonly those with a northern exposure. The trees all show, in their stunted, gnarled, and twisted trunks, the severity of their struggle for existence on these barren slopes. In the lower valleys the sagebrush (*Artemisia*) and rabbit brush (*Bigelovia*) constitute almost the sole vegetation. Grasses occur in scattered tufts but are apparently mostly dead during the summer. In the past the East Tintic Mountains have supported sufficient of this scanty herbage to afford range for cattle, horses, and sheep, but grazing to-day is limited to occasional small herds of cattle and horses along the mountain slopes.

GEOLOGY.

GENERAL GEOLOGIC FEATURES.

The East Tintic Range is composed of Paleozoic sedimentary and Tertiary igneous rocks. The sedimentary rocks are quartzite, over 6,000 feet thick, overlain by 6,500 to 7,000 feet of limestone, including a small amount of shale. The igneous rocks are in part intrusive rhyolite porphyry and monzonite and in part effusive rhyolites and latites or andesites.

The isolated position of the range permits only a general correlation of its formations with those of neighboring ranges, which also consist principally of Paleozoic strata. The Oquirrh Range, to the north, and the Canyon Range, to the south, seem closely related structurally as well as stratigraphically. The Oquirrh Mountains comprise two great unsymmetrical anticlines separated by a syncline.[1] The Paleozoic rocks of the Canyon Range are folded into several anticlines and synclines.[2] The part of the East Tintic Mountains lying northwest of the area shown in Plate IV is structurally a broad anticline which, in the mining district, is paralleled by an unsymmetrical syncline of northward pitch, with a vertical or slightly overturned west limb and a gently dipping east limb. Exposures to the south and east are interrupted and largely concealed by the extensive masses of igneous rocks, but the small areas of exposed strata east of the syncline indicate an anticline beneath Long Ridge and the head of Goshen Valley, and still another anticline of southward pitch, exposed in the canyon of Currant Creek east of the Tintic quadrangle. The east limb of this anticline extends in limestone almost to the base of Mount Nebo, of the Wasatch Range. To the west, across Tintic Valley, are exposures of westward-dipping quartzite, with a few intercalated limestone beds, which stratigraphically lie above any of the formations studied in the East Tintic Mountains. Their attitude is that of a southwestern continuation of the west limb of the anticline northwest of the Tintic quadrangle; but it must be remembered that one or more large faults may separate the two places. The Paleozoic rocks are thus considerably folded, and the axes of the folds have a general northerly trend. This structure appears to extend beyond the limits of the range, both longitudinally and transversely.

Faulting in the district is very prevalent, though its relation to Great Basin topography, as shown on page 16, is not very clear, owing to the advanced stage of erosion. Most of the observed faults have nearly east or northeast trends; a few trend northwest. They range in horizontal displacement from less than a foot to as much as 500 feet—in one fault 2,000 feet. Faults of northerly trend are believed to be abundant also, but as a rule their existence can not be proved on the surface because they parallel the strike of the rock. Fissuring and faulting obviously took place at several different times from the post-Jurassic uplift to the later part of the Tertiary period, and many faults are older and others younger than the period of ore deposition. The systems of faults, both the older and the younger, determine the location of certain ore bodies, but several of the more pronounced faults have no connection with the trends of ore shoots and had evidently become healed before ore deposition began.

[1] Emmons, S. F., in Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2 pp. 360, 361, 1895.

[2] Loughlin, G. F., A reconnaissance in the Canyon Range, west-central Utah: U. S. Geol. Survey Prof. Paper 90, pp. 53–58, 1914.

SEDIMENTARY ROCKS.

FORMATIONS REPRESENTED.

The sedimentary rocks exposed within the Tintic quadrangle have a total thickness of at least 13,000 feet. They include Cambrian, Ordovician, Devonian, and Mississippian strata, interrupted by unconformities at the top of the Cambrian and at the base of the Mississippian. The formations shown in Plate I are separated so far as possible according to paleontologic evidence; in Plate IV they are subdivided chiefly on lithologic grounds, to elucidate geologic structure and show where necessary, the stratigraphic relations between the country rocks of different mines.

In the earlier report all the present recognized formations from the middle of the Ophir formation to the top of the Opohonga limestone were included in the "Mammoth" or "Eureka limestone," and all from the base of the Bluebell dolomite to the top of the Pine Canyon limestone were included in the "Godiva limestone." Measured sections presented in that report show seventeen recognized members in the "Eureka limestone" and twenty-six in the "Godiva," but apparently no use was made of them as an aid in working out the structure. In the present report only fifteen divisions of the limestone are recognized, and these have been distinguished on lithologic grounds largely because of their usefulness in solving structural and stratigraphic problems. Some, like the Dagmar limestone, are of uniform character and sharply contrasted with all the other formations; others, like the Teutonic limestone, are highly variable and can not be recognized until the beds above and below have been determined. Beds of similar lithologic character occur at many different horizons, and failure to recognize this and other facts has led to the location of some claims in geologically unpromising places. For these reasons the different limestone formations are described in considerable detail and are distinguished on the map (Pl. IV). Correlations of the names used in the earlier and present reports are shown in the following table.

Correlation of formation names used in Tintic reports.

Earlier report.		Present report.		
Name.	Thickness in feet.	Name.	Thickness in feet.	Age.
Humbug formation	250	Humbug formation	250	Upper Mississippian.
Godiva limestone	2,216	Pine Canyon limestone Gardner dolomite Victoria quartzite	1,000 435–700 0–85	Lower Mississippian. Unconformity.
		Pinyon Peak limestone [a]	0–150	Upper (?) Devonian.
		Bluebell dolomite	700–1,100	Upper to Lower Ordovician.
Mammoth (or Eureka) limestone.[b]	[c] 3,970	Opohonga limestone Ajax limestone, including Emerald dolomite member.	825+ 570	Lower Ordovician. Unconformity.
		Opex dolomite	390	Upper (?) Cambrian.
		Cole Canyon dolomite Bluebird dolomite Herkimer limestone Dagmar limestone Teutonic limestone	510 175–200 235 100 556	Middle Cambrian.
		Ophir formation	355	
Tintic (or Robinson) quartzite.	7,000	Tintic quartzite	6,000+	Lower Cambrian; may possibly include some pre-Cambrian.

[a] At Pinyon Peak the Bluebell dolomite is 1,100 feet or more thick and is overlain by about 150 feet of Pinyon Peak (Devonian) limestone. No Devonian strata are present in the Tintic mining district proper.

[b] In the annual report (p. 622) the name "Eureka limestone" was used; in the folio the name "Mammoth limestone" was used.

[c] The difference in recorded thickness shown by corresponding parts of the table is due to repetition of certain strata by faulting, not recognized in the earlier report.

CAMBRIAN SYSTEM.

TINTIC QUARTZITE (LOWER CAMBRIAN).

DISTRIBUTION.

The Tintic quartzite is the lowest formation of the stratigraphic series. It forms Quartzite Ridge and extends from that ridge in a north-northwesterly direction beyond the northwest corner of the quadrangle. (See Pls. I and II.) Its dip, averaging about vertical on Quartzite Ridge (see Pls. IV and V), is steep to the east north of Eureka Gulch and gradually flattens northwestward, crossing an anticlinal axis and changing to west beyond the limits of the quadrangle. South of Mammoth Gulch the formation is represented by numerous inclusions in the monzonite and by small isolated areas emerging through the lava flows nearly to the south boundary of the quadrangle. It is also exposed in a few places on Long Ridge, south of Goshen Valley.

There is a small area of quartzite emerging through rhyolite about 2 miles southeast of Homansville. Quartzite has also been struck three-fourths of a mile farther south, in the Tintic Standard shaft, where it extends from the 700-foot to and beyond the 1,000-foot level. The rock in both these places has the lithologic character and stratigraphic relations of the Tintic quartzite. At the road fork 1½ miles south of the Tintic Standard shaft a considerable thickness of the Ophir formation indicates that the Tintic quartzite must lie a short distance below the surface, as suggested in Plate II, sections A–A′ and B–B′.

The quartzite inclusion just north of the Martha Washington shaft (see Pl. IV) can not be definitely correlated. It may be equivalent to the small quartzite beds in metamorphic limestone south of the Lower Mammoth mine, with which it is in line, or may be regarded as a block of the Tintic quartzite. In the latter case it is necessary to assume that the block was carried up by the ascending monzonite magma a vertical distance of about 2,000 feet, or that it is a remnant of a large mass first upfaulted and later invaded by the monzonite.

LITHOLOGY.

The Tintic quartzite is best exposed on Quartzite Ridge, between Eureka and Mammoth gulches. The typical rock is grayish white to very pale pink, has a fine, even grain, and is composed almost wholly of quartz. Indications of bedding are in many places absent, owing to its uniform purity and in part to excessive jointing. It is thoroughly broken up by three or more systems of vertical sheet joints which have divided the rock into thin slabs from an inch or so to 2 or 3 feet in thickness. Three systems are recognized—(1) strike N. 70° E., dip 55° N. to 90° and 55° S., somewhat slickensided; (2) strike N. 10° E., dip 75° to 80° E.; (3) a flat system dipping about parallel to the general surface of the ridge crest.

There are a few variations from the type described above. Several thin conglomerate beds are found throughout the formation and are well exposed in the lower portion along the cuts of the Denver & Rio Grande Railroad. The pebbles are well rounded, range in diameter from less than one-fourth of an inch to 1 or 2 inches, and consist mostly of vein quartz, though a few of quartzite were found. Crush breccia is also occasionally found along fracture or fault zones. Its fragments, in contrast to the conglomerate pebbles, are sharply angular and are cemented by pale-brownish, rather argillaceous and perhaps calcareous material. In the easternmost railroad cut in the lower part of Eureka Gulch (west of the area shown on Pl. IV) there are a few insignificant slate bands from 2 inches to 1 foot thick. Eastward from the summit of the ridge a few pebbly beds occur, but the rock as a whole gradually becomes slightly argillaceous and thin bedded, with finely micaceous partings, one-fourth of an inch apart. On the weathered surface it develops fine yellow to rusty bands or spots, which may be concealed by a black lichen growth. This variety passes conformably but abruptly into the brown-weathering, highly micaceous and calcareous sandstone and shale at the base of the Ophir formation. Ripple marks were found on a few talus fragments along the southeast slope of Quartzite Ridge, and some exposures, especially those in the lower part of Mammoth Gulch, showed cross-bedding in places. Cross-bedding is also conspicuous in the zone of thin intercalated conglomerate beds in the upper part of the formation on Quartzite Ridge.

In the northwest corner of the Tintic quadrangle, along the range front near the 7,000-foot contour, the quartzite includes a bed with dark reddish-brown weathered surface that has been traced for about 2 miles along the strike. Its thickness where seen is 8 to 10 feet but is said to be considerably greater in places. The

unweathered rock, which has been exposed in a few prospect holes, is green. An analysis shows it to contain 63.5 per cent SiO_2, 5.1 per cent Al_2O_3, and 18.4 per cent iron (or 26.3 per cent Fe_2O_3). It has been mistaken for a gossan or "iron outcrop" and has been called a fissure vein, but it is really a bed in the quartzite containing an unusually large amount of iron.

The following microscopic description of the typical quartzite is quoted from the report of the earlier survey:[1]

> Microscopic studies show it to be a very pure quartzite, the individual grains being well rounded and for the most part of very uniform size. Occasionally the grains are somewhat drawn out, as if by dynamic metamorphism. Corroded grains are not common, though present. In rare cases the quartz shows crystal facets. In many of the grains of quartz are particles of a dark material so abundant as to give the individual grains a very dirty appearance. The nature of these particles could not be determined. The lowest beds of quartzite contain some feldspar and muscovite, while nearly all of the beds show zircon and rutile. In one specimen from the upper portion greenish grains were observed tinged with brown on the rim, which were thought to be glauconite.

The quartzite inclusions in the monzonite are in places rather coarse grained, and one or two of them contain garnets along some of the bedding planes. The general character of these inclusions indicates that they are the somewhat metamorphosed equivalent of the upper beds on Quartzite Ridge. Several prospect holes have been opened in or along these intrusions, as if prospectors had mistaken quartzite for vein quartz. The two may readily be distinguished, the quartzite having a distinctly granular structure and the vein quartz being either massive or filled with small crystalline pockets and stained with iron oxide.

CORRELATION.

Although the Tintic quartzite itself contains no fossils, its thickness and position at the base of the stratigraphic series place beyond reasonable doubt its correlation with the Cambrian quartzites of the Wasatch, Oquirrh, and House ranges in Utah, at least in part. At Ophir Canyon, in the Oquirrh Mountains, Emmons[2] found Lower Cambrian trilobites in the overlying clay slates. In the House Range and in Big Cottonwood Canyon of the Wasatch Mountains, Walcott[3] also found Lower Cambrian fossils in the overlying shale. In the Blacksmith Fork section of the northern Wasatch Mountains, Walcott found the same lithologic sequence but obtained Middle Cambrian fossils in the overlying shale. Middle Cambrian fossils were found by Weeks in the overlying shale at Tintic. The upper part of the Tintic quartzite, therefore, may be Middle Cambrian, but its intermediate geographic position between the House and Wasatch ranges suggests that its top is very near the boundary between Middle and Lower Cambrian.

The exposed thickness of the Tintic quartzite is estimated to be more than 6,000 feet. Its base is not exposed. This great thickness is in marked contrast to the thickness of Cambrian quartzite elsewhere in Utah. In the Big Cottonwood Canyon section, in the Wasatch Mountains, there is a series of quartzites, shales, and conglomerates with a total estimated thickness of 12,000 feet; but Blackwelder[4] has recently shown that only the upper 1,500 feet or so of relatively pure quartzite is of undoubted Cambrian age, and that it rests unconformably upon the remainder, which he assigns to the Algonkian. Hintze[5] has more recently stated that the quartzite above the unconformity is only 700 feet thick. In the Onaqui and Simpson mountains, west of the Tintic district, the same general relations—pure quartzite with intercalated beds of limestone carrying Cambrian fossils above a great thickness of relatively impure quartzite, shale, and conglomerate—were found by the writer during reconnaissance work in 1912. No special search for an unconformity and no measurements of thickness were made. The upper quartzite, however, is far from being 6,000 feet thick. The quartzite exposed in the House Range and Blacksmith Fork sections is less than 1,500 feet thick and has no features suggestive of pre-Cambrian age. In comparison with this evidence, the Tintic quartzite is of sufficiently uniform character and purely quartzose composition to be classed as Cambrian, but it is much thicker than any completely exposed sections of Cambrian quartzite. It therefore remains an open question whether the deposition of sandy sediment in Cambrian time began earlier and progressed much more rapidly or longer in the Tintic district than

[1] U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 620, 1899.

[2] Emmons, S. F., in Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 362, 1895.

[3] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, No. 5, p. 171, 1908.

[4] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 20, pp. 520-523, 1910.

[5] Hintze, F. F., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, p. 103, 1913.

elsewhere, or whether a considerable part of the Tintic quartzite in reality includes strata of pre-Cambrian age, much more purely quartzose than in other sections and essentially identical in character with the Cambrian quartzite. A search for evidence of an unconformity in the quartzite was made on Quartzite Ridge, but nothing was found except a few small, well-rounded quartzite pebbles.

the contact is obscured by talus, has in places developed relations suggestive of unconformity. This is especially true north of Eureka Gulch, where much of the slate, in two places all of it, has been overridden by the quartzite, or the slate has been locally thinned and bulged by compression during folding.

Its continuation south of Mammoth Gulch is represented by a few blocks of black hornfels included in the monzonite. East of Knightville the 700-foot level of the Tintic Standard mine shows about 20 feet of decomposed shale overlying quartzite. A considerable thickness of shale in the stratigraphic position of the Ophir was noted by the road fork to the south of the Tintic Standard. It is also exposed east of the Tintic quartzite on Long Ridge.

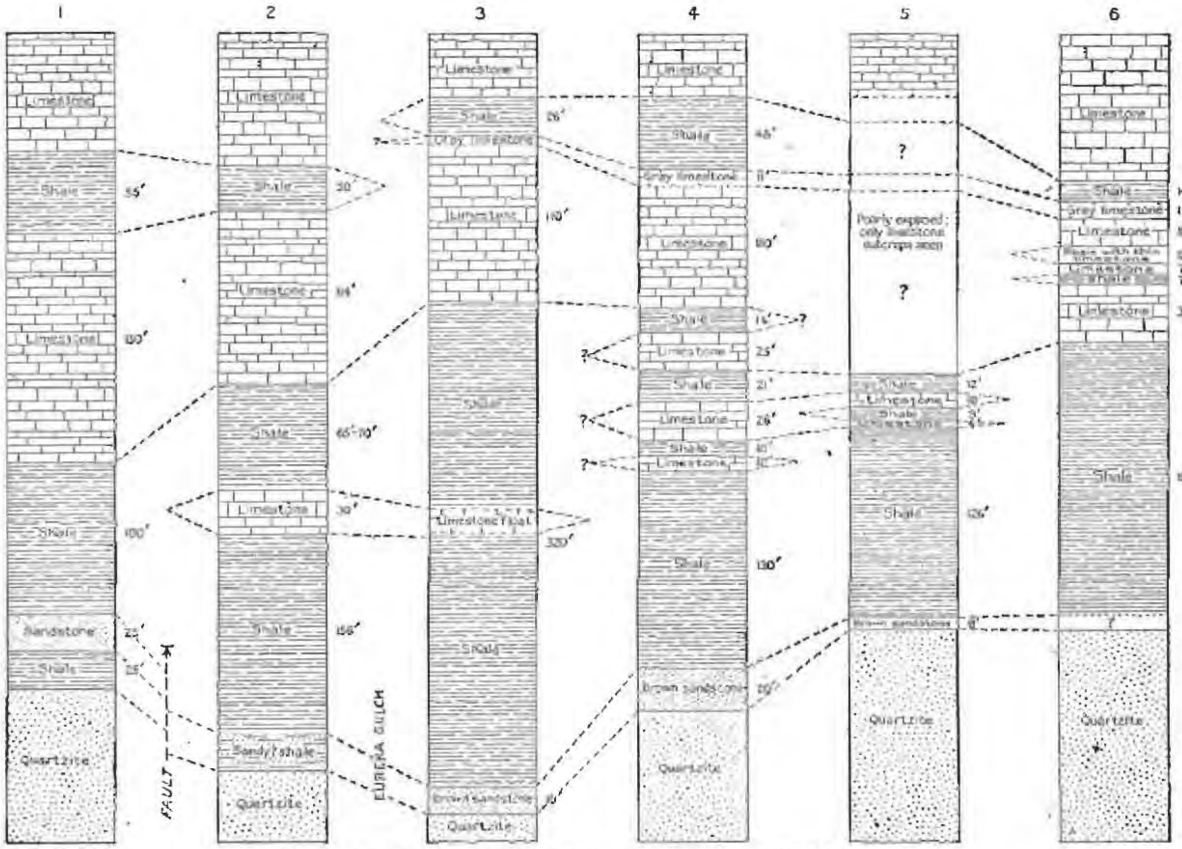


FIGURE 4.—Sections showing variations in strata of the Ophir formation.

OPHIR FORMATION (MIDDLE CAMBRIAN).

DISTRIBUTION.

The Ophir formation, named from the mining town in the Oquirrh Mountains,[1] comprises shales, or locally slates, and a little sandstone, with intercalated beds of limestone. It crops out as a narrow band along the east side of the Tintic quartzite. Its relations to the quartzite, where the contact is well exposed, are conformable; but compression faulting, especially where

THICKNESS.

The thickness of the Ophir formation appears to vary greatly, as shown on the map (Pl. IV) and in figure 4. The apparent variations are due partly to faulting, most of the faults on the quartzite contact not extending across the slates into the intercalated or overlying limestone beds. Variations in true thickness are

[1] The name Ophir formation has been proposed by B. S. Butler, of the United States Geological Survey, with whom the writer was associated during 1912 and 1913 in a study of the ore deposits of Utah. The formation is nearly everywhere present in the ranges of central Utah, overlying the quartzite, and at Ophir is not only well exposed and of definitely determined age but is also of considerable economic importance. The lower part of the formation at Ophir is Lower Cambrian, the remainder Middle Cambrian.

also shown in figure 4, section 2 of which shows the upper slate bed pinching out. This may be an original feature or a secondary local effect of compression. The marked difference between the lower slate members of sections 1 and 2 is also thought to be due largely to faulting or compression, that in section 1 being either overridden by the quartzite or more probably locally thinned. Just north of the locality of section 2, where the quartzite contact swings westward, a prospect hole has exposed slate overridden by quartzite. The slate is also overridden at a place half a mile north of Eureka Gulch and at another place three-fifths of a mile north of Jenny Lind Canyon (Pl. I). At the latter place a prospect shaft starts in quartzite, but its dump shows only the limestone that overlies the shale, proving that the quartzite forms only a veneer over shale and limestone. No exact comparison can be made between sections 2 and 3, on opposite sides of Eureka Gulch, but it seems probable that the upper slate beds in each mark the same horizon. Sections 3 and 4 and probably section 6 are definitely correlated by a thin but persistent bed of gray massive limestone underlying the upper slate, and the lenslike character of the different lower members is strongly suggested. The thickness in these sections, measured from the top of the Tintic quartzite to the top of the uppermost slate bed, is in section 1, 355 feet; section 2, 400 feet; section 3, 475 feet; section 4, 403 feet; section 5, 159 feet (+?); section 6, 297 feet. A section measured on Long Ridge, east of Goshen Valley, during the earlier survey gave slate 450 feet, quartzite (brown micaceous sandstone?) 150 feet, slate 200 feet; total, 800 feet. Whether this measurement denotes apparent or true thickness is not stated. The limits of the formation are arbitrary, as the intercalated limestone beds are identical in character with beds in the overlying Teutonic limestone.

LITHOLOGY.

The impure sandstone near or at the base of the formation is green where fresh to dark brown where weathered, fine grained, thin bedded to slaty, and more or less slickensided in the direction of the strike. Its conspicuous minerals are quartz and ferruginous calcite, and the weathering out of calcareous cement from among the grains leaves fine rust specks of ferric oxide.

The shale or slate is like the sandstone in color, is in many places banded, and for the most part shows marked cleavage or fissile structure in one or two directions, usually at low angles to the banding. It is slightly to markedly micaceous. The banding is due to alternation in the composition of successive layers, the chief noticeable difference being in the amount of calcium carbonate. Some layers are almost free from it; others are nearly pure limestone and are miniature intercalated limestone beds.

The limestone beds are dark bluish gray to nearly black, banded or mottled with light brown, and in places weather to a red residual soil. It appears from the presence of prospect holes in red ground that the color may have been mistaken for mineralization, but the color is due to red clay impurity or perhaps to some iron carbonate in the original rock and is not necessarily connected with ore deposition. Most beds are more or less distinctly banded. Some are very strongly striped or ribboned, the ribbons ranging from one-eighth of an inch to 2 inches in thickness; others are so thinly banded as to become shaly and to give a mottled effect on weathering. Some thin beds or lenses are spotted on the weathered surface with dark concretionary growths ranging from grains the size of a pea down to typical oolitic particles. These spotted beds especially tend to weather to a red residual soil. All the specimens tested effervesce briskly when touched with dilute hydrochloric acid. The dark-weathering bands are somewhat carbonaceous but as a rule less argillaceous than the light-weathering bands, which are highly argillaceous or arenaceous.

CORRELATION.

The Middle Cambrian age of most of the Ophir formation in the Tintic district was proved in 1905 by Weeks, who found *Obolus mcconnelli* and *O. rotundatus* 100 feet above the top of the Tintic quartzite. Walcott,[1] on the evidence of these fossils, doubtfully correlates the slates at Tintic with the Howell formation (chiefly impure limestone but including a shale member at its base) of the House Range section, about 80 miles to the southwest. The lithologic variations of the formation in the Tintic region, however, would correlate the thick lower shale with the Pioche shale (Lower

[1] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 158, 196, 1912. Fossils (No. 34 n) found by F. B. Weeks, 1905.

Cambrian)[1] of the House Range, the middle limestone member with the Langston (?) limestone, and the uppermost shale with the shale at the base of the Howell formation. The contrast between paleontologic and lithologic evidence is shown in the correlation table opposite page 31 and in figure 5. The beds in the Tintic region have not yet yielded fossils by which they may be correlated with the Blacksmith Fork section of northeastern Utah,[2] but lithologically, as well as stratigraphically, they are approximately equivalent to the Langston limestone and the lower part of the Ute limestone. Walcott also regards the formation provisionally, on paleontologic evidence, as equivalent to the shale and limestone 100 to 325 feet above the Lower Cambrian quartzite in the Big Cottonwood Canyon section of the Wasatch Mountains. The lowest 100 feet of the slate in the Tintic district may be, like the lower beds at the type locality, Ophir, of Lower Cambrian age.

TEUTONIC LIMESTONE (MIDDLE CAMBRIAN).

The Teutonic limestone, named from Teutonic Ridge, is in fact an upward continuation of the limestone members of the Ophir formation and is well exposed from the town of Robinson, in the lower part of Mammoth Gulch, northward except where it is overlain by a short arm of rhyolite west of Packard Peak. It is also exposed south of the road fork east of Burriston Canyon (Pl. IV) and presumably on Long Ridge. The following sections show its thickness as well as its variations and resemblance to the limestone members of the Ophir:

Sections of Teutonic limestone.

1. Saddle east of Quartzite Ridge.

[A continuation of section 1 of Ophir formation. (See fig. 4.)]

	Feet.
5. Dark-gray finely banded argillaceous limestone, cross-bedded in upper part, weathering light gray	114
4. Dark-blue limestone with countless veinlets	77
3. Fault breccia	30
2. Dark bluish-gray limestone with countless veinlets	170
1. Dark bluish-gray limestone, thinly bedded, ribboned, or mottled with bands or small blotches of yellowish-brown argillaceous material	175
	566

2. Spur northwest of Dagmar shaft.

[A continuation of section 4 of Ophir formation.]

	Feet.
7. Same as No. 5 in section 1	268+
6. Dark-blue mottled shaly or thin-bedded limestone	
5. Limestone like No. 5 in section 1, weathering light gray	24
4. Dark-bluish limestone with light-brownish bands	87
3. Mottled shaly limestone	26
2. Dark-bluish limestone with dark spots size of pea on weathered surface	64
1. Dark-blue limestone strongly striped with yellowish-brown bands	95
	564+

The spotted (pisolitic) variety (No. 2 of section 2) is especially characteristic north of Eureka Gulch, where it forms thin lenses or beds. From Jenny Lind Canyon northward it is considerably silicified in places and leaves a reddish soil on weathering. The mottled shaly and thin-bedded dark-blue varieties are perhaps the most conspicuous. In places the shaly blotches or bands, usually yellowish brown, have weathered pink or red, and the rock is identical in appearance with parts of the Herkimer and Opohonga limestone. Where faulting has offset the different beds, as north of Eureka Gulch, these close resemblances may easily cause confusion in the stratigraphy. It is only by location of the Dagmar limestone and the top shale member of the Ophir formation that the mottled shaly variety of the intervening Teutonic limestone can be accurately determined. A thin, very fine grained siliceous bed was noted north of Jenny Lind Canyon just south of the rhyolite contact. The Teutonic limestone has not yet yielded any fossils but lies between known Middle Cambrian beds.

DAGMAR LIMESTONE (MIDDLE CAMBRIAN).

The argillaceous Dagmar limestone, named from the Dagmar mine, extends, with interruptions by numerous faults, from Mammoth Gulch to the north boundary of the Tintic quadrangle, although from Jenny Lind Canyon northward it is for the most part concealed beneath rhyolite and débris. It is also poorly exposed south of the road fork in the East Tintic Cambrian area and also just below the East Tintic Development Co.'s shaft. Its thickness is close to 100 feet throughout the mining district proper, but at the north boundary of the quadrangle it is only about 75 feet thick. Its color on fresh fracture varies in different layers from medium to dark gray, but

[1] L. D. Burling (Canada Geol. Survey Mus. Bull. 2, Geol. ser. 17, pp. 120-124, 1914) has recently discussed the age and extent of the Pioche shale and maintained that in the House, Oquirrh, and central Wasatch mountains its lower 100 feet is Lower Cambrian and the remainder Middle Cambrian. It is possible that the lower 100 feet of the Ophir formation, which is nonfossiliferous, may be Lower Cambrian.

[2] Walcott, C. D., op. cit., pp. 148-153.

its weathered surface is a uniform yellowish to grayish white (Pl. XI, *A*). Some parts are finely banded and dark; others consist of alternating lenses or layers of dense oolitic medium gray rock, with a few conspicuous grains of white calcite suggestive of fossil remnants. No recognizable fossils have yet been found.

Other beds in the district also weather nearly white, but they are more dolomitic and none are nearly so thick as the Dagmar bed. The Dagmar limestone is therefore the most distinctive horizon marker among the lower formations in the district, and it is this bed which serves more than any other to correlate the strata north and south of Eureka Gulch. It is also a sure indicator of faulting, as shown by the distribution of faults indicated on the map (Pl. IV). Numerous faults doubtless exist elsewhere, but the inclosing strata are too uniform or too indistinctive in character for their detection.

HERKIMER LIMESTONE (MIDDLE CAMBRIAN).

The Herkimer limestone (see Pl. XIII, *C*) lies along the east side of the Dagmar limestone as far as the south wall of Jenny Lind Canyon, where it underlies a thin covering of red soil. From this locality northward it is concealed beneath débris, except along the divide near the northwest corner of the quadrangle. It is named after the Herkimer shaft, east of Quartzite Ridge. It is also present in the limestone areas of the East Tintic district and east of Burriston Canyon. Its thickness is from 225 to 235 feet, although in the second saddle east of Quartzite Ridge repetition by faulting gives it an apparent thickness about 100 feet greater. It is for the most part the typical mottled shaly limestone, consisting of bluish-black dense carbonaceous limestone, mottled by thin discontinuous layers or blotches of yellowish-brown material rich in iron and clay. The blotches in places pass from yellowish-brown into reddish shades and give the rock a striking resemblance to the Opohonga limestone. It also resembles a large part of the Teutonic limestone. No fossils have been found in the Herkimer limestone.

BLUEBIRD DOLOMITE (MIDDLE CAMBRIAN).

DISTRIBUTION AND THICKNESS.

The Bluebird dolomite is well exposed along the crest of the southward-sloping spur east of the Herkimer shaft (see Pl. XI, *B*) and is easily traced over the crest of the ridge and down the north slope to the General Logan shaft, where it bends sharply westward and becomes lost in a confusion of fault blocks and breccia. North of Eureka Gulch and west of Cole Canyon it is well exposed along the backbone of Bluebird Spur for nearly 3,000 feet, but farther north it is largely concealed beneath débris, though outcrops on spurs west and southwest of Porphyry Flat and along the divide in the northwest corner of the quadrangle prove its continuity. It is also present in the East Tintic area, north of Burriston Canyon, where its stratigraphic position is considerably obscured by faulting. The thickness, roughly measured, on the west slope of the peak west of Eureka Peak is about 175 feet. In the northwest corner of the quadrangle it is about 200 feet. The apparent greater thickness in places north of Eureka Gulch is due largely, if not wholly, to the fact that the dip of the bedding and the slope of the surface are in the same direction.

LITHOLOGY.

The typical rock (see Pl. XII, *A*) is a dark bluish-gray fine-grained dolomite spangled with short white rods averaging 10 millimeters (two-fifths of an inch) in length and 1 or 2 millimeters in width. Individual grains of the rock proper average 0.2 to 0.3 millimeter; those of the white rods are slightly coarser. The rock proper shows practically no effervescence with cold dilute hydrochloric acid, but the white rods give moderate effervescence, proving the mixture of some free calcite with the dolomite. When dissolved in hot acid, the rock leaves a black carbonaceous residue and gives a distinct odor of hydrogen sulphide. The white rods are straight or slightly curved and may be the remains of crinoid stems or corals, but no trace of original fossil structure is preserved. A few beds at higher horizons, especially in the Opex dolomite and Ajax limestone, duplicate the Bluebird dolomite in appearance, but they are all much thinner and the rocks underlying and overlying them are of different types.

COLE CANYON DOLOMITE (MIDDLE CAMBRIAN).

DISTRIBUTION AND THICKNESS.

The Cole Canyon dolomite is best exposed on the first summit west of Eureka Peak and is readily traced southward and northward to Mammoth and Eureka gulches, respec-

A. SPECIMEN OF DAGMAR LIMESTONE.

B. OUTCROP OF BLUEBIRD DOLOMITE EAST OF HERKIMER SHAFT.

A. SPECIMEN OF BLUEBIRD DOLOMITE SHOWING THE CHARACTERISTIC WHITE MARKINGS.

B. SPECIMEN FROM AJAX DOLOMITE SHOWING RELATION BETWEEN FOSSIL REMNANTS AND CLOUDING OF SURFACE.

tively, although near Eureka Gulch it is considerably offset by faulting, and its characteristic appearance is greatly obscured by brecciation and reddish discoloration. There is a small exposure in contact with the intrusive Swansea rhyolite in Mammoth Gulch at the east end of Robinson village. North of Eureka Gulch the formation is largely concealed, but the scattered exposures along the upper west slope of Cole Canyon are sufficient to prove its continuity to and beyond the north boundary of the quadrangle, as shown on the maps (Pls. I and IV). It is also exposed in the East Tintic district east and southeast of Knightville. Its thickness, measured just north of the Southern Eureka shaft, is 500 to 510 feet, the top and bottom being arbitrarily placed at the lowest and highest light-colored bed.

LITHOLOGY.

The formation consists of a number of alternating beds, from 10 to 25 feet thick, with nearly white and dark-gray weathered surfaces. The whitish weathered beds are medium to light gray on fresh fracture. Some are dense and finely banded, resembling some parts of the Dagmar limestone; others are very finely crystalline, single grains averaging about 0.2 millimeter in diameter, with scattered coarser white grains or patches, some of which suggest fossil remnants and others short veinlets of dolomite and calcite in healed fractures. When dissolved in hot hydrochloric acid the dense finely banded variety proves to be rather argillaceous, leaving small quantities of a light brownish-gray clay residue, and the finely crystalline variety proves to be a pure dolomite, leaving practically no residue.

The dark bluish-gray variety is still darker on fresh fracture and finely crystalline, single grains averaging 0.2 millimeter or less in diameter. Some beds show fine banding, and others obscure mottling or clouding; still others are of uniform color and texture. This variety includes a few thin fragmental layers (intraformational conglomerates) and a few thin shaly beds. The typical rock when dissolved in hot hydrochloric acid leaves a considerable residue of black carbonaceous material and gives off an odor of hydrogen sulphide. A partial analysis from one of these beds, given on page 623 of the earlier report, is as follows: SiO_2, 8.77; Fe_2O_3, 0.49; CaO, 27.22; MgO, 18.53; CO_2 (calculated), 41.77; total, 96.78 per cent. A few white grains or patches have outlines indicative of fossils, as do also some small growths of chert; but the only recognizable fossils were found by Weeks in 1905.

CORRELATION.

The only fossil species identified is *Obolus mcconnelli*, found by Weeks 1,700 feet above the top of the Tintic quartzite. A similar fossil (*Obolus* sp.) was found at the same horizon by the writer in 1913. Walcott,[1] on the strength of this evidence, correlates the beds provisionally with the Marjum limestone (the c member), between 2,225 and 2,475 feet above the thick basal quartzite in the House Range section. These relations are shown in the correlation table and in figure 5 (p. 31).

OPEX DOLOMITE (UPPER? CAMBRIAN).

DISTRIBUTION.

The Opex dolomite, named from the Opex mine, includes several beds, mostly dark gray or bluish gray but of varying texture, none of which are sufficiently distinctive to be trustworthy horizon markers in working out the local stratigraphy. For this reason its position in the field can be determined only by recognition of the Cole Canyon and the Emerald dolomite beds below and above it. It is as a whole poorly exposed. A continuous section can be studied along the saddle west of Eureka Peak, where its top is marked by a thin bed of shale overlain by a bed of limestone conglomerate; but north and south of this place it is mostly concealed by débris in draws and gulches. Part of it is probably present south of Mammoth, but its identity there has been destroyed by contact metamorphism. The thin quartzite beds south of Mammoth, shown on the map (Pl. IV), approximately mark its top in this vicinity. North of Eureka Gulch the Opex dolomite is concealed by the alluvium in Cole Canyon and by débris-covered slopes farther north but is moderately well exposed on the top of the broad spur south of Porphyry Flat. Its boundaries as shown on the map of the mining district (Pl. IV) are therefore largely estimated and not actually located. Near the north boundary of the quadrangle little or none of it is present, and strata of probable Ordovician age rest upon the Cole Canyon dolomite. In the East Tintic district it caps the low hill

[1] Walcott, C. D., op. cit., pp. 156, 197.

at the northwest end of the limestone area and may be obscurely exposed beneath the Ordovician on the north side of Burriston Canyon.

THICKNESS AND LITHOLOGIC VARIATIONS

The exposed thickness and lithologic variations west of Eureka Peak are shown below:

Section of Opex dolomite west of Eureka Peak.

	Feet.
Limestone conglomerate marking local base of Ajax limestone.	
5. Dark shaly limestone, mottled or thinly banded, with thin beds of true shale. Resembles the Herkimer limestone and parts of the shaly Opohonga limestone	85
4. Dark-gray granular dolomite, somewhat cross-bedded	92
3. Light-gray granular dolomite, similar to the Emerald member of the Ajax limestone, alternating with and grading upward into greenish and reddish shale	26
2. Dark shaly limestone	13–18
1. Dark-gray dolomite; some beds mottled, some with short white spangles (like the Bluebird dolomite), some granular and finely cross-bedded, some spotted either with small dark included fragments or with carbonaceous spots left by destroyed fossils	172
	388–393

This section represents a portion of the limestone which has probably been locally thinned by squeezing and faulting, and whose upper boundary is an obscure erosion surface. The map (Pl. IV) and section (Pl. V, section B–B′) show the existence of obscure north-south faults and also a greater thickness of the beds in the lower workings of the Opex. The beds here are partly bulged by local contortions and flexing and probably also by the presence of a downfaulted wedge, but the data at hand are not sufficient to afford a detailed interpretation of the structure, and the true thickness of the formation is therefore not known. The formation is not well enough exposed anywhere else in the district to permit a check on the measurements given.

The above section shows that any of the members may be confused with other formations if lithologic character alone is considered.

CORRELATION.

Weeks in 1905 found fossils in the Opex dolomite about 2,000 feet above the Tintic quartzite, or somewhere within members 2 to 5 in the section just given, which he designated Upper Cambrian. These fossils were found about 300 feet above the Middle Cambrian fossiliferous beds in the Cole Canyon dolomite. The boundary between Middle and Upper Cambrian, however, can not be definitely located within this 300-foot interval and is drawn arbitrarily at the uppermost colored bed in the Cole Canyon dolomite.

OBSCURE UNCONFORMITY AT THE TOP OF THE UPPER CAMBRIAN.

Evidence of an unconformity at the top of the Upper Cambrian, though meager at any one place, is convincing when considered as a whole. The presence of quartzite and of limestone conglomerate with rounded pebbles (intraformational conglomerate is also present) at the base of the Ordovician (Ajax limestone) points to emergence at certain localities. Pebbles of Middle to Upper Cambrian limestone have also been found in some conglomerate layers of the Opohonga limestone, which overlies the Ajax limestone. A noteworthy occurrence of this kind is in the isolated limestone area east of Knightville, where scattered pebbles typical of the Bluebird dolomite and a few higher Cambrian horizons are embedded in argillaceous limestone. The largest of the pebbles noted was 4 inches in diameter. Their presence shows that the Cambrian strata were exposed to erosion during a considerable part of Lower Ordovician time.

No angular discordance in the dip of beds has been found to mark the exact position of the unconformity, but the varying thickness and local absence of the Upper Cambrian, together with the evidence just presented, strongly suggest that although there is little or no discordance in dip, some irregular break separates the Upper Cambrian from the Lower Ordovician strata.

The extent of the unconformity beyond the limits of the East Tintic Range is not known, as Ordovician strata have not been recognized in the neighboring ranges and are probably lacking in at least some of them. In the extreme northern and the southwestern parts of Utah, as well as in eastern Nevada, Ordovician strata are reported as resting conformably on Upper Cambrian strata. The unconformity between the Cambrian and Ordovician of the Tintic district is therefore evidently confined to central Utah, but nothing more can be said of its areal extent.

REGIONAL CORRELATION OF THE UTAH CAMBRIAN.

The accompanying correlation table gives a comparison of the Tintic Cambrian with Wal-

Correlation of Cambrian sections in Utah.

Geologic age.	House Range.		Tintic district.	
Ordovician.	Thin-bedded bluish-gray and and purple limestone resting conformably on the Cambrian (285 feet).		Ajax limestone. Unconformity	Abs
Upper Cambrian.	*Feet.* 11. Notch Peak limestone...... 1,490 10. Orr formation (limestone and shale)............... 1,825	3,315	*Feet.* 8. Opex dolomite...................... 390	Abs
Middle Cambrian.	9. Weeks limestone........... 1,390 8. Marjum limestone.......... { 550 / 250 / 300 7. Wheeler formation (limestone and shale).......... 570 6. Swasey formation (limestone and shale)............... 340 5. Dome Canyon limestone.... 355 4. Howell formation (chiefly limestone, including Spence shale, 30 feet thick, at base)............ 455 3. Langston (?) limestone..... 205	4,417	7. Cole Canyon dolomite.......... 510 6. Bluebird dolomite............. 175 5. Herkimer limestone............ 235 4. Dagmar limestone.............. 100 3. Teutonic limestone............ 556 2. Ophir formation (shale and limestone)........................ { 255 / 100 1,931	4. Lim 3. Shal
Lower Cambrian.	2. Pioche formation (shale and sandstone)............... 125 1. Prospect Mountain quartzite (base not exposed).... 1,375+	1,500	1. Tintic quartzite (base not exposed).. 6,000+ Total Cambrian, possibly including some pre-Cambrian.. 8,321+	2. Shal 1. Quar
	Total Cambrian..........	9,232+		Unc
Pre-Cambrian.			....................(?)......................	Quar

a The unconformity at the base of the Big Cottonwood Canyon section was found by Blackwelder in 1910. F. F. Hintze (A contribution to the geology of the Wasatch shale and Devonian limestone and correlated it tentatively as Ordovician. L. D. Burling, however (Early Cambrian stratigraphy in the North American Cordillera: Cana limestone. To judge from its moderate thickness, the limestone is probably all of Middle Cambrian age, and both Upper Cambrian and Ordovician are absent from the Big

Correlation of Cambrian sections in Utah.

Tintic district.	Big Cottonwood Canyon.[a]	Blacksmith Fork.
mestone.	Absent (?).	Ordovician limestone, conformably above the Cambrian.
ormity		
Feet. olomite........................ 390	Absent (?).	Feet. 7. St. Charles limestone................ 1,227
nyon dolomite.......... 510 d dolomite............. 175 er limestone............ 235 limestone.............. 100 ic limestone............ 556 ormation (shale and lime- 255)........................ 100 — 1,931	Feet. 4. Limestone............................ 481 3. Shale................................ 150	6. Nounan limestone........... 1,011 5. Bloomington formation (limestone and shale)............ 1,320 4. Blacksmith limestone......... 570 3. Ute limestone (including the Spence shale member, 30 feet thick, at base)......... 759 2. Langston limestone........... 498 Total Middle Cambrian above quartzite..... 4,188
		1. Brigham quartzite........... 1,232+ Total Middle Cambrian (possibly including some Lower Cambrian)........................ 5,420+
uartzite (base not exposed).. 6,000+ otal Cambrian, possibly including some pre-Cambrian.. 8,321+	2. Shale...................... 100 1. Quartzite.................. 1,000± — 1,100± Total Cambrian.............. ?	........................(?)........................ Total Cambrian (base not exposed)........................ 6,647+
	Unconformity	
............(?)......................	Quartzite and shale................. 10,500+	

F. F. Hintze (A contribution to the geology of the Wasatch Mountains: New York Acad. Sci. Annals, vol. 23, pp. 105–106, 1913) found 481 feet of limestone between the Cambrian
mbrian stratigraphy in the North American Cordillera: Canada Geol. Survey Mus. Bull. 2, p. 101, 1914), states that he and F. B. Weeks found Middle Cambrian fossils in this
oth Upper Cambrian and Ordovician are absent from the Big Cottonwood Canyon section.

cott's Cambrian sections in the House and Wasatch ranges.[1]

The contrasts in thickness are more clearly shown in figure 5. No satisfactory correlation of the basal quartzite is yet possible, owing to the great difference between its thickness and that of other (completely exposed) sections of Cambrian quartzite. If the Tintic quartzite can be proved to be wholly Cambrian, its great

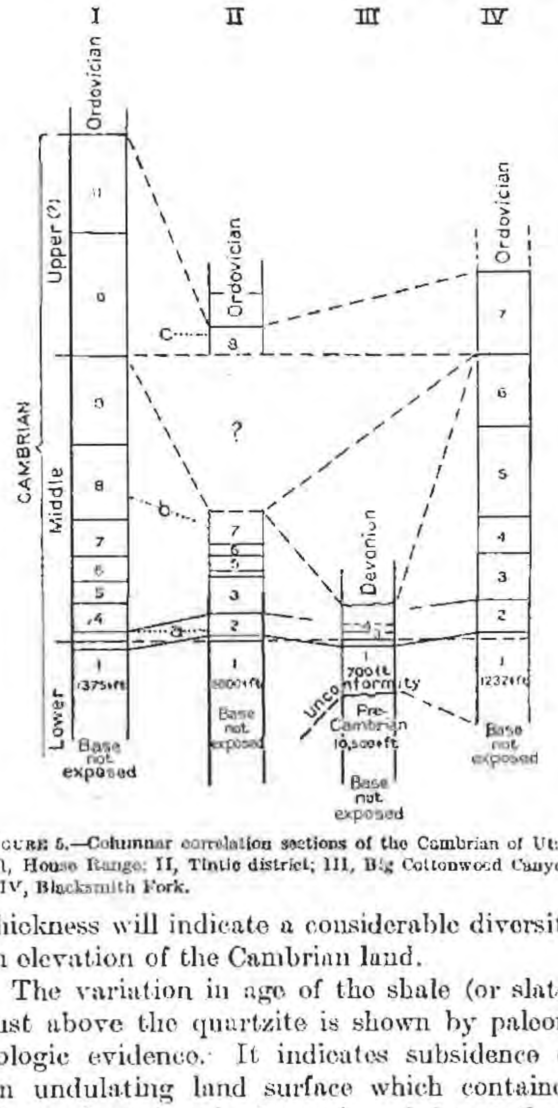


FIGURE 5.—Columnar correlation sections of the Cambrian of Utah. I, House Range; II, Tintic district; III, Big Cottonwood Canyon; IV, Blacksmith Fork.

thickness will indicate a considerable diversity in elevation of the Cambrian land.

The variation in age of the shale (or slate) just above the quartzite is shown by paleontologic evidence. It indicates subsidence of an undulating land surface which contained elevated portions in the region of the northern Wasatch and Onaqui ranges and possibly in the Tintic district. Comparison of the composition of the Middle Cambrian rocks in the House Range, Blacksmith Fork, and Tintic sections shows a relative abundance of shale in the first two and of dolomite in the last. There is also a marked difference in thickness. The first two are about equal, and each is over twice as thick as the Tintic Middle Cambrian. The localities are too widely separated to warrant an unreserved explanation, but it is pertinent to point out certain possible relations to be tested by future work. Either the Tintic district was much farther from land than the other two and received less material, as suggested by the correlation of fossils; or else it must have been elevated above sea level during a part of Middle Cambrian time, and in that case there may be at Tintic a concealed unconformity, either within the Middle Cambrian or between the Middle and Upper Cambrian.

The Tintic Upper Cambrian is less than one-third as thick as the Upper Cambrian of the Blacksmith Fork section and less than one-eighth as thick as that of the House Range section. These differences are evidently due to the Cambrian-Ordovician unconformity in the Tintic district.

ORDOVICIAN SYSTEM.

AJAX LIMESTONE (INCLUDING THE EMERALD DOLOMITE MEMBER).

DISTRIBUTION AND THICKNESS.

The Ajax limestone, named from the Ajax mine, is for the most part a dark bluish-gray cherty magnesian limestone but includes, 90 feet above its base, a creamy-white dolomite bed of considerable stratigraphic and structural importance, here named the Emerald dolomite member, after the Emerald mine.

The lower 90 feet of the formation consists of dark-gray clouded dolomite or higldy magnesian limestone, partly cross-bedded and partly consisting of thin conglomeratic beds, containing many thin lenses and nodules of light-gray chert. The dark clouding or mottling in beds near the base is of interest owing to its association with fossil remnants—white, partly silicified rodlike and branching fragments resembling annelid borings. (See Pl. XII, *B*.) These fragments have broad black borders, more carbonaceous than the rest of the rock. In some of these fragments none of the original fossil is now visible, but the carbonaceous mottling marks its former presence. Besides carbonaceous matter hydrogen sulphide is also present and can be detected by its odor when the rock is broken or dissolved. The cross-bedded and conglomeratic character and the presence of the quartzite beds south of Mammoth are of special interest as partial indications of an unconformity.

[1] Walcott, C. D., op. cit., pp. 148-158.

The Emerald dolomite member is a persistent bed of almost pure dolomite, for the most part fine grained but containing small patches and veinlets of coarser grain. It is from 30 to 40 feet thick and is continuously exposed from Mammoth to Eureka. Near the Centennial Eureka shaft it is offset westward for about 1,000 feet by a combination of faults. North of these faults it lies just west of the Centennial Eureka and Eureka Hills shaft but is mostly concealed beneath débris. North of Eureka Gulch it is almost entirely concealed but has been recognized along the west slope of the 7,778-foot peak on the divide in the northwestern part of the Tintic quadrangle. South of Mammoth its identity has been destroyed by contact metamorphism.

The limestone above the Emerald dolomite member is mostly fine grained, cherty, and high in magnesia. Its upper part, however, is distinctly calcareous, as shown by the following analysis, quoted from the earlier report:[1] SiO_2, 4.33; Fe_2O_3, 0.63; CaO, 52.34; MgO, 0.60; CO_2 (calculated), 41.78; total, 99.68 per cent. It is well exposed throughout the district from Mammoth northward to a point within a mile of the north boundary of the quadrangle. Close to this boundary it seems to have locally thinned or to have merged in appearance with the overlying Opohonga limestone, which is here unusually thick. It is also present southeast of Mammoth, but its character in that area is much obscured by metamorphism. It has been noted at the southeast extremity of the Ordovician area just north of Burriston Canyon and along the southeast base of Pinyon Peak.

The best exposures in the mining district are on the spurs extending southward from Eureka Peak and northward past the Centennial Eureka shaft house. Its upper part merges so gradually into the Opohonga limestone that no definite boundary can be drawn, and measurements of thickness, even in sections near together, differ by several feet. The transition is well shown on the west slope of Eureka Peak. Here the typical cherty limestone passes into a rather thin band of shaly limestone of the Opohonga type; this is followed by a rather fine to coarse grained gray limestone, which in turn passes into a lighter-gray variety containing thin lenses of chert; the latter passes into the shaly Opohonga limestone, the lower beds of which are cherty. As nodules and thin lenses of chert are the characteristic feature of the greater part of the Ajax limestone, the difficulty of determining its upper boundary is obvious. The thickness between the Emerald dolomite member and the lowest shaly limestone of the Opohonga type is about 440 feet. North of Eureka Gulch there is less variation of texture in the upper part of the Ajax but the lower beds of the Opohonga limestone are more persistently cherty and the line must be drawn according to the relative prominence of cherty or shaly character. The contact east of the Black Warrior prospect and to the north may be anywhere within a zone 100 feet wide.

[1] Op. cit., p. 624.

AGE AND CORRELATION.

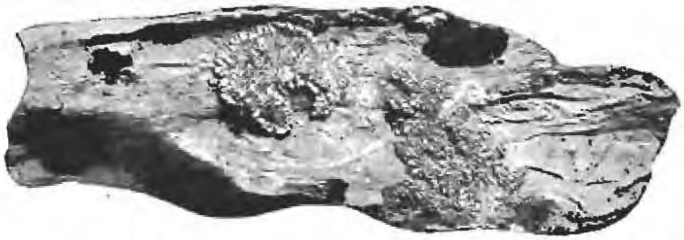
The only fossils found in the Ajax limestone were a few poorly preserved gastropods collected at the southeast base of Pinyon Peak. These have been determined as *Straparollus?* sp. by Edwin Kirk, who states that they strongly suggest a form found in the Pogonip limestone of Nevada. The occurrence of lower Pogonip fossils in the overlying Opohonga limestone thus places the Ajax limestone close to the base of the Ordovician.

OPOHONGA LIMESTONE (LOWER ORDOVICIAN).

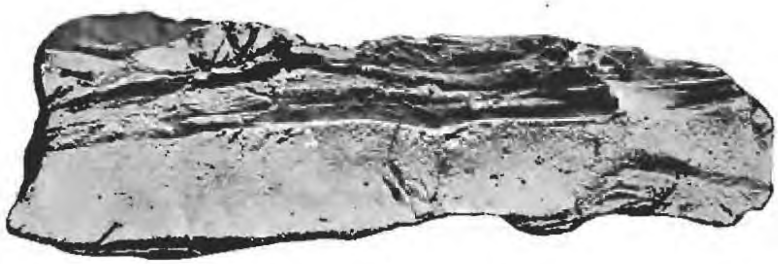
DISTRIBUTION AND THICKNESS.

The mottled shaly Opohonga limestone, named from the Opohonga mine, is persistent and is easily identified by its characteristic appearance and relatively great thickness. It can be traced with no interruptions, except in Eureka and Mammoth gulches, from the north boundary of the district to the East Star prospect, a mile southeast of Mammoth. Southeast of Mammoth its base is obliterated by contact metamorphism and mineralization, which have affected a greater and greater thickness until at the East Star prospect only the topmost beds can be identified. It is also present in the East Tintic district, forming the isolated limestone area east of Knightsville and parts of the Ordovician strata around Burriston Canyon, Homansville Canyon, and the lower east slope of Pinyon Peak. The exposure at Burriston Canyon has been subjected to metamorphism and has lost most of its distinctive characteristics.

The indefinite location of the lower contact of the formation, with the Ajax limestone, has already been mentioned. Its upper contact, though conformable, is sharply de-



A.



B.

SPECIMENS OF OPOHONGA LIMESTONE SHOWING VARIATIONS IN TEXTURE.

C. SPECIMEN OF HERKIMER LIMESTONE SHOWING CHARACTERISTIC MOTTLING.

fined. The thickness at Eureka Peak is 825 feet. At Mammoth, east of the Sioux Ajax tunnel, the thickness of the recognizable rock is approximately 740 feet, the difference of 85 feet being perhaps due in large part to the indefiniteness of the lower contact and to the effects of contact metamorphism. In the northern part of the district, west of the Paxman shaft, the thickness is approximately 700 feet, but at the north boundary of the Tintic quadrangle the formation appears to be at least 1,000 feet thick, though, as already suggested, this thickness may include a considerable part of the Ajax limestone, which is there poorly defined.

LITHOLOGY.

This rock has a striped to mottled or mosaic appearance (see Pl. XIII, *B*, *C*), bands or short lenses of medium to light gray limestone alternating with bands of yellow to red argillaceous material. These colors, however, are due to surface weathering; the rock in the underground workings of the Eagle and Blue Bell and the Victoria mines is of uniformly light-gray color ("white lime") and is not at first easily recognized. It is characteristic for the gray limestone to form eye-shaped bodies, or short lenses, from 1 inch to 2 or 3 inches long, separated by finely banded ribbons of yellow to red shaly material. The prominence of red coloring is as a whole persistent and in this respect the Opohonga limestone differs from the Teutonic and Herkimer; but where the Opohonga is deficient in red or where the other two limestones show unusually large amounts of it, the three may be easily confused. The gray limestone bands or lenses of the Opohonga limestone are as a rule of lighter shade than those of the other two, though this difference is not constant and is not a safe criterion for distinguishing among them; but where colors are confusing the great relative thickness of the Opohonga limestone and its contacts with the cherty Ajax limestone below and the Bluebell dolomite above serve to identify it beyond dispute.

Another noticeable feature of the Opohonga limestone is the great number of thin beds of conglomerate it contains, most of them intraformational. The fragments included in the conglomerate are flakes of the gray limestone, and their occurrence suggests that thin layers of the calcareous mud after deposition were exposed to drying and shrinkage and became cracked into flaky fragments which were moved and redeposited when the next layer was formed. No mud cracks or other marks characteristic of such conditions have been identified, but the nearly vertical position of the beds is not favorable for their exposure even if any are present.

Other conglomerate beds contain rounded pebbles representing underlying formations. The best example noted is in the isolated area east of Knightville, where there are a few pebbles, the largest 4 inches in diameter, of dark-bluish dolomite with white spangles typical of certain Middle and Upper Cambrian beds. The significance of these pebbles in connection with the Cambrian-Ordovician unconformity is stated on page 30.

The rock effervesces briskly when touched with cold dilute hydrochloric acid and develops a furrowed surface owing to the more rapid solution of the less argillaceous laminae. When completely dissolved it leaves a large residue of dark-gray to light-brownish clay. This brief chemical test is the safest means of distinguishing the rock underground from light-gray members of the overlying Bluebell dolomite. The latter gives little or no effervescence on fresh surfaces and leaves only a small gray residue.

CORRELATION.

A few poorly preserved fossils were found on the east slope of Eureka Peak, about 100 feet below the base of the Bluebell dolomite. These have been determined by Edwin Kirk as *Dalmanella* cf. *D. hamburgensis* Walcott, *Cyrtolites* sp., *Ophileta* sp., and *Asaphus* sp. (fragments), and are assigned by him to the lower Pogonip. (See paragraph on correlation of the Bluebell dolomite, p. 35.) One very poorly preserved gastropod was found north of Burriston Canyon. This also suggests the Ordovician but is otherwise indeterminable. In color and texture the rock (see table facing p. 30) has some resemblance to the 285 feet of Ordovician limestone which conformably overlies the Cambrian in the House Range, and it is also similar in general appearance to much of the Pogonip limestone of Eureka, Nev. These lithologic similarities, though not trustworthy data for

correlation in themselves, are of interest in connection with the paleontologic data.

BLUEBELL DOLOMITE (LOWER TO UPPER ORDOVICIAN).

DISTRIBUTION.

The Bluebell dolomite, named from the Blue Bell mine, is the most extensively exposed formation in the Tintic district proper. It crops out continuously from the base of Packard Peak southward to Eureka Gulch; a small isolated patch is barely exposed in the middle of the gulch; from Eureka it extends southward to the head of Mammoth Gulch, and thence it swings southeastward as far as Sioux Pass, where it is covered by volcanic rocks. In the East Tintic district it is exposed both north and south of Burriston Canyon, but its characteristic appearance is largely destroyed by bleaching and partial recrystallization due to slight contact metamorphism. It is also exposed on both sides of Homansville Canyon and makes up the greater part of Pinyon Peak.

THICKNESS.

The base of the Bluebell dolomite is everywhere sharply defined against the Opohonga limestone. Its top is marked in most places by a thin quartzitic band (the Victoria quartzite), which has been noted at intervals from the northern part of the district southward to the slope below Mammoth Bluff and which is regarded as the basal formation of the Mississippian, resting unconformably on the Ordovician. Where this quartzite band is not exposed it is impossible to separate the Bluebell sharply from the lower beds of the Gardner dolomite (Mississippian) and the upper limit is arbitrarily drawn at the highest exposed light-colored bed. On Pinyon Peak the Bluebell dolomite is overlain by the Pinyon Peak limestone of Devonian age.

The thickness of the Bluebell dolomite can not be accurately stated. It is approximately 900 feet north of Eureka and it appears to be only 700 feet east of Eureka Peak; but in many places it appears much greater, owing to local flattening of the dip, to probable faulting, or to actual variations in thickness caused by the unconformity at its top. The most conspicuous of these places is the spur northeast of the Mammoth mine, where the apparent thickness is more than double that east of Eureka Peak. No faults of considerable size could be recognized here on account of the general uniformity of the beds, but the rock is much shattered and contorted. The overlying Victoria quartzitic beds show no pronounced offset, and the only reasonable way to account for the great local thickness of the Bluebell dolomite is by attributing it in part to the unconformity and assuming the occurrence of block faulting which has caused repetition of the beds, as suggested in Plate V, section B–B. The apparent difference in amount of offset along the mapped faults north and south of the Mammoth mine is due to the flatter position of the beds near the southern fault.

In the northwestern part of the Tintic quadrangle, about half a mile from the north boundary, the thickness is at least 1,000 feet. On the east slope of Pinyon Peak a rough estimate gives 1,100 feet or more, but the upper 400 feet may include Silurian or Devonian strata. On the long spur north of Pinyon Peak the total apparent thickness seems to have been increased by faults, but the faults are concealed, and the exact conditions can be determined only by very detailed work beyond the limits of the quadrangle.

LITHOLOGY.

The Bluebell dolomite comprises an alternating series of beds that weather light and dark bluish gray, mostly of fine-grained but in part of medium to coarse grained texture. The fresh surfaces of both are medium to dark gray or bluish gray. Some beds, especially of the lighter variety, are finely banded. Some dark beds are mottled with extra dark carbonaceous blotches. Both varieties so far as tested are dolomitic, yielding almost no effervescence when touched with dilute hydrochloric acid. The difference in the color of their weathered surfaces is due to the presence of more carbonaceous matter in the darker variety. Some of the lighter-colored beds are practically pure carbonate; others when dissolved leave a small gray residue of clay. Between 100 and 200 feet above the base of the formation, throughout the district, the beds, both light and dark, contain a number of small nodules and thin seams of chert. There are also in places small patches, many of white sparry dolomite and some of chert, which are evidently altered fossil fragments; but no identifiable fossils have been found associated with them. The Bluebell dolomite resembles the Cole Canyon dolomite in general lithologic character but can be distinguished by its

greater thickness and by the character of the formations below and above it.

Certain local conditions, however, are likely to cause confusion of these two similar formations. Thus the Eureka Gulch fault has placed the Bluebell dolomite on the north almost directly in line with the Cole Canyon dolomite on the south, and the fact that ore channels have been followed across the gulch without conspicuous offset may easily lead to correlation of the two dolomites as parts of one formation; but the succession of formations, as shown in Plate IV, proves that the two are in fact different. Another chance for confusion of the two dolomites exists in the East Tintic district, north of Burriston Canyon, where faulting has brought the two near together and contact metamorphism has obscured their characteristic appearance as well as that of the intervening strata.

CORRELATION.

Two lots of poorly preserved fossils were found in the Bluebell dolomite directly east of Eureka Peak. The specimens in the first lot, from the bottom bed, have been identified by Mr. Kirk as *Maclurea annulata* Walcott and *Helicotoma* sp. He states regarding these and the fossils found in the Opohonga limestone:

> Although the fossils are poor they show that these faunas are undoubtedly of Beekmantown (Lower Ordovician) age. In the West they can be correlated with the lower Pogonip of Nevada, the Garden City limestone of northeastern Utah, and the El Paso limestone of Texas.

The second lot, found in the middle part of the dolomite on the summit of a low knob, contained only one recognizable form, *Solenopora* sp. One specimen of *Orthis* sp. was found on the north side of Homansville Canyon just below the basal Mississippian beds. Regarding these two fossils Mr. Kirk says:

> The fossils in these two lots indicate post-Beekmantown Ordovician. *Solenopora*, supposedly a calcareous alga, is typically post-Beekmantown, and the *Orthis* finds its closest ally in rocks of Stones River age. It is probable that the upper Pogonip carries post-Beekmantown Ordovician, with which these beds may be correlated.

On the southeast slope of Pinyon Peak a few indeterminable gastropods and a specimen of *Streptelasma* sp. were found at horizons 400 feet and more below the top of the dolomite. The *Streptelasma*, according to Mr. Kirk, "points clearly to the Richmond age of the containing beds. They may be correlated with the Lone Mountain limestone of the Eureka district, Nev., and the Fish Haven dolomite of northeastern Utah."

The Bluebell dolomite therefore ranges from lower to Upper Ordovician, and it is possible that the upper 400 feet at Pinyon Peak may include Silurian or Devonian strata. The generally uniform character of the formation, however, and the rather widely separated horizons at which fossils of critical stratigraphic value have been found leave no convenient means for dividing it definitely into members.

According to Richardson[1] the Lower to Upper Ordovician is represented in northern Utah in the vicinity of Bear Lake by the following strata, named in ascending order: Garden City limestone, 1,000 feet thick; Swan Peak quartzite, 500 feet thick; and Fish Haven dolomite, 500 feet thick. According to Weeks[2] Ordovician beds, including limestone overlain by quartzite, are present in the northern part of the Wasatch Mountains and range in thickness from 500 to 2,000 feet in the country east of Ogden, but thin and, in places, disappear south of the latitude of Salt Lake City.

The writer[3] failed to find any strata equivalent to the Ordovician of the Tintic district during reconnaissance work in the southern half of the Wasatch Mountains, and Emmons and Spurr[4] did not recognize any in the Oquirrh Mountains. In the House Range[5] only 285 feet, topping the Cambrian section, has been left by erosion. In the San Francisco and adjacent districts of southern Utah, according to Butler,[6] limestone and dolomite of Lower Ordovician age are present, passing upward into limy shale and quartzite. In the section at Eureka, Nev.,[7] the type locality of the Pogonip limestone, the Pogonip is 2,700 feet thick and consists of a basal series of interstratified limestone, argillaceous beds, and sandy beds, which pass upward into distinctly bedded purer fine-grained bluish-gray lime-

[1] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 407–410, 1913.

[2] Weeks, F. B., Phosphate deposits in the western United States: U. S. Geol. Survey Bull. 315, p. 451, 1906; also Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, p. 359, 1910.

[3] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 436–452, 1913.

[4] Spurr, J. E., Economic geology of the Mercur mining district, Utah, with introduction by S. F. Emmons: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 362, 1895.

[5] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, p. 153, 1912.

[6] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 28–32, 1913.

[7] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 13, 1892.

stones. The typical Pogonip section is thus much thicker than its equivalent in the Tintic district and consists of highly fossiliferous limestone, whereas the Tintic section is poor in fossils and its upper part is dolomitic. In the passage from a lower impure to an upper purer and distinctly bedded limestone, the two sections are similar.

DEVONIAN SYSTEM.

PINYON PEAK LIMESTONE (UPPER? DEVONIAN).

The only recognized Devonian rock in the Tintic district is a band of shaly limestone about 150 feet thick, exposed along the upper eastern slope of Pinyon Peak from its blunt eastern spur southwestward to its base (Pl. I) and designated the Pinyon Peak limestone. It was not seen on the north spur of the peak. On the east spur of the peak it is separated from the base of the Mississippian by a very slight angular unconformity and rests conformably upon the Bluebell dolomite. On the north spur the basal quartzitic beds of the Mississippian rest on dolomite of Ordovician or later age, and to the south, at Homansville Canyon, the Mississippian rests on Middle Ordovician dolomite.

The Pinyon Peak limestone is very similar in general lithologic character to the Opohonga limestone. Its bedding surfaces present many markings, including mud cracks, flattened shaly flakes, and possible worm trails. Fine fossil fragments are also abundant but only a few recognizable forms were found. These were determined by Mr. Kirk as *Pleurotomaria* sp., *Cyathophyllum* sp., *Rhombopora* sp., and *Spirifer* sp. They indicate Upper Devonian (Threeforks?) age, but none of them are of sufficiently critical value to render this correlation final.

As already suggested, the upper 400 feet of the underlying dolomite may be wholly or in part of Devonian age and in that case may be correlated, on both stratigraphic and lithologic grounds, with the Jefferson dolomite.

The occurrence of Devonian strata in the Tintic district is of interest as an indication of the former continuity of the Devonian over an area in which it has heretofore not been found. The Jefferson dolomite (or limestone) has been shown by Kindle [1] to extend southward into Utah, and beds at both the Jefferson and Threeforks horizons have been identified in the Randolph quadrangle of northern Utah by Richardson.[2] Strata equivalent in stratigraphic position and lithologic character have been found by Blackwelder as far south as Mount Morgan, in northeastern Utah,[3] and recently Hintze [4] has described a series of fossiliferous Devonian strata 1,000 feet thick, which he correlates with the Jefferson, in the Cottonwood mining district of the central Wasatch Range. This series rests in apparent conformity below Mississippian beds, but contains no strata suggestive of Threeforks age.

The nearest occurrences of Devonian strata to the south and west of the Cottonwood district are, so far as published descriptions show, in the San Francisco district of southwestern Utah and the Eureka district of eastern Nevada. In the San Francisco district Butler [5] has found a dolomitic limestone, 1,500 feet thick, of undetermined age (Silurian?, Devonian?), overlain by a calcareous fossiliferous shale, 50 feet thick, which rests conformably beneath the Mississippian. The fossils in the shale prove it to be Upper Devonian. In the Eureka district, Nev., Hague [6] found 6,000 feet of Lower to Upper Devonian limestone overlain by Upper Devonian shale. The Tintic Devonian helps to bridge the gap between these two localities and those in the Wasatch Mountains, but its thinness compared to the other sections suggests that the Devonian sea was in places unusually shallow and may not have been continuous over central Utah.

The ranges immediately west and south of the East Tintic Mountains do not, so far as reconnaissance surveys by the writer have shown, present any sections within which Devonian strata are to be expected, and therefore they throw no light on the problem.

UNCONFORMITY AT THE BASE OF THE MISSISSIPPIAN.

The presence of an unconformity at the base of the Mississippian in Utah has not been gen-

[1] Kindle, E. M., The fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, vol. 4, No. 20, 39 pp., June 5, 1908.

[2] Richardson, G. B., The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., vol. 36, pp. 407–412, 1913.

[3] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 527–528, 1910.

[4] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 108–109, 1913.

[5] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 29–35, 1913.

[6] Hague, Arnold, Geology of the Eureka district, Nev: U. S. Geol. Survey Mon. 20, pp. 13, 63–84, 1892.

erally recognized, but the evidence in the Tintic district is proof of its existence, and data from other places indicate that it extends well over the central part of the State. The irregularity and local disappearance of pre-Mississippian strata in the Wasatch Mountains has been attributed by Weeks[1] mainly to nondeposition, although Blackwelder[2] mentions "an obscure and probably unimportant unconformity" near or at the base of the Mississippian east of Ogden. No other mention has been published, so far as the writer is aware, of any unconformity at the base of the Mississippian, but in the Tintic district the lithologic character of the Victoria quartzite and its slightly unconformable position upon the Pinyon Peak limestone, together with the general absence of the Pinyon Peak and the variation in thickness of the Bluebell dolomite beneath it, indicate that an erosional unconformity exists.

The present general uniformity in strike and dip of the Mississippian beds and the older strata in contact with them shows that the pre-Mississippian strata must have lain nearly or quite horizontal while the Mississippian was being deposited. They must have been elevated in late Devonian time and submerged in early Mississippian time, without conspicuous folding. Some idea of the amount of erosion during this short period of elevation can be gained from the variation in thickness of the pre-Mississippian strata. In the northwestern part of the Tintic quadrangle the Bluebell dolomite is at least 1,000 feet thick, but in parts of the mining district proper it is only 700 feet thick. At Pinyon Peak it is at least 1,100 feet thick and is overlain by 150 feet of Devonian limestone; at Homansville Canyon, 1½ miles to the southward, it is only about 500 feet thick, and this implies that a thickness of 750 feet of strata was removed by Devonian and Mississippian erosion.

This amount is indicative of a moderately irregular topography and, together with the general absence of the Pinyon Peak limestone elsewhere in the district, suggests strongly that the unconformity extends far beyond the limits of the Tintic quadrangle. The evidence set forth below lends strong support to this statement. The writer's observations in the Wasatch Mountains from Mount Nebo northward to the Cottonwood district[3] have shown the Mississippian limestone resting on Middle Cambrian limestone at several places. In North Canyon, in the Mount Nebo ridge, and at Santaquin the relations, to judge from lithologic evidence, are much the same as at Homansville Canyon, in the East Tintic Mountains. In the Provo and American Fork districts the thickness of pre-Mississippian limestone is much less, and in places the Mississippian may even rest on the shale just above the Cambrian quartzite; but in the Cottonwood district, 4 or 5 miles farther north, 1,000 feet of Devonian limestones are present between Mississippian and Middle Cambrian strata.[4] No evidence of angular unconformity has been found here, but the absence of shaly Upper Devonian limestone may be of some significance. In the Uinta Mountains Emmons[5] and Weeks[6] found the Mississippian limestone resting in part on Ordovician quartzite and in part on Cambrian shale, the Ordovician pinching out.

In the northern Wasatch[7] and Bear River Plateau[8] regions all ages from Lower Cambrian to Mississippian are represented, and no unconformity has been recognized in them other than the obscure one mentioned by Blackwelder (see above), where Devonian strata underlie the Mississippian. In the Oquirrh Mountains Butler[9] has found only 1200 feet of limestones, presumably Cambrian, between the Cambrian quartzite and fossiliferous Mississippian limestone. Here again no positive evidence of an unconformity is known. The writer, during reconnaissance work in ranges west and south of the East Tintic Mountains, found only Cambrian and Mississippian formations and did not find these in contact, except perhaps along an obscure overthrust in the West Tintic mining district. There are no data at hand to explain the absence of intervening formations in these

[1] Weeks, F. B., and Ferrier, W. F., Phosphate deposits in western United States: U. S. Geol. Survey Bull. 315, p. 451, 1906.

[2] Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: U. S. Geol. Survey Bull. 430, p. 539, 1910.

[3] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains: Jour. Geology, vol. 21, pp. 436-452, 1913.

[4] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 108-113, 1913.

[5] Emmons, S. F., Uinta Mountains: Geol. Soc. America Bull., vol. 18, p. 296, 1907.

[6] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, pp. 432-438, 1907.

[7] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains: Geol. Soc. America Bull., vol. 21, pp. 518 et seq., 1913. Blackwelder's section is based on the work of several writers, to whom he refers.

[8] Richardson, G. B., Am. Jour. Sci., 4th ser., vol. 36, pp. 406-416, 1913.

[9] Butler, B. S., oral communication to the writer.

ranges. In the Lakeside Mountains, west of Great Salt Lake, the writer in a hasty trip found Mississippian limestone resting on beds similar to the Opohonga (Ordovician) dolomite of the Tintic section, but no fossils were found to prove the age of these beds, and there was no opportunity to study the contact.[1] In the San Francisco district, in the southwestern part of the State, Butler [2] found Ordovician, Silurian,[3] and Devonian strata present in conformable succession, aggregating about 9,350 feet in thickness, and conformably overlain by the Mississippian. In the Eureka section of eastern Nevada Ordovician, Silurian, and Devonian strata are present, aggregating 13,000 feet. An unconformity exists there within the Ordovician,[4] but none was noted between the Devonian and Mississippian ("Lower Carboniferous").

The evidence just cited points to an elevation during late Devonian time of land in the central part of the State, but not in the extreme northern and southern parts and possibly not in the western part. The central area corresponds reasonably well with the Utah land,[5] or "positive element," in Schuchert's paleogeographic maps. This land suffered erosion sufficient to remove the Devonian completely in some places and much or all of the Ordovician in a few places, and it underwent a general submergence in early Mississippian time. The failure to find exposures of pronounced angular unconformity in the Wasatch country leaves the evidence not entirely convincing, but the dissimilarity between neighboring stratigraphic sections in the areas here noted, when considered in connection with the more detailed evidence in the Tintic quadrangle, is strongly indicative of unconformity.

It may be of interest before dismissing the subject to recall the evidence of uplift in central Utah at several periods during Paleozoic time. The tentative correlation of the Ophir formation with the Howell instead of the Pioche formation of the House Range suggests a very slight elevation of the present Tintic district at the end of Lower Cambrian time. The much smaller total thickness of the Tintic Middle Cambrian section in comparison with those of the House and northern Wasatch ranges, though not offering convincing evidence, may imply an elevation in central Utah during a great part of Middle Cambrian time. The Cambrian-Ordovician unconformity in the Tintic district is proof of another, possibly the third period of local elevation. The absence or at least the marked thinness of Silurian and Lower Devonian dolomite in the Tintic district indicates either a local emergence of land or a shallowing of the sea between the Ordovician and late Devonian. The Devonian-Mississippian unconformity marks possibly the fifth, and, according to available evidence, the most extensive emergence of land in central Utah prior to the deposition of Mississippian strata.

CARBONIFEROUS SYSTEM (MISSISSIPPIAN SERIES).

VICTORIA QUARTZITE (LOWER MISSISSIPPIAN).

DISTRIBUTION AND THICKNESS.

The Victoria quartzite, named from the Victoria mine, is of small but variable thickness and includes alternating beds of limy quartzite and siliceous limestone, some of them conglomeratic. They are noteworthy as the markers of an unconformity between the Mississippian and older strata. The quartzitic beds do not form conspicuous outcrops and are easily overlooked; furthermore, their succession and composition vary from place to place, and in some exposures at the proper horizon distinct quartzitic beds may be missing. Scattered outcrops have been noted from a point near the north boundary of the district as far south as the slope below Mammoth Bluffs, where it is cut off by a strong fault which on its south side has carried all post-Ordovician strata above the present erosion surface.

The thickness of the quartzitic beds on the slope below Mammoth Bluffs was measured by Tower and Smith [6] as follows:

	Feet.
26. Sandy limestone, quartzitic at base	10
25. Gray limestone	25
24. Sandy limestone and quartzite	50
	85

On the spur between Eagle and Gardner canyons a zone of approximately the same

[1] Hintze (op. cit., p. 106) states that the Lower Ordovician (Beekmantown) horizon is represented in the Lakeside Mountains.

[2] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 28 et seq., 1913.

[3] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 13, 1892.

[4] The Lone Mountain limestone, assigned to the "Upper Silurian" by Hague, is now regarded as Upper Ordovician and Silurian, containing fossils of Richmond and Niagaran ages, according to Edwin Kirk.

[5] Schuchert, Charles, Paleogeography of North America: Geol. Soc. America Bull., vol. 20, p. 464, pl. 49, 1910.

[6] Op. cit., p. 625.

thickness contains conglomeratic beds in addition to those of quartzite and sandy limestone.

On the north wall of Homansville Canyon, in its middle portion, about 250 feet above the railroad, the horizon of the beds is represented by a few small exposures of conglomeratic beds that separate fossiliferous Mississippian limestone from Middle Ordovician dolomite, but these beds can not be traced any considerable distance owing to the talus and brush which cover the slopes extending northward from the canyon. Along the railroad two-fifths of a mile farther east the horizon is marked by two or three quartzite beds, 2 to 4 feet thick, alternating with limestone; the lowest quartzite bed rests on Ordovician dolomite. East of the summit of Pinyon Peak there is only one limy quartzite bed, less than 2 feet thick; on the north slope of the peak there are two thin quartzite beds separated by one of limestone conglomerate containing light-gray subangular pebbles that resemble the lighter members of the Ordovician dolomite. Thin beds of quartzite also mark the base of the Mississippian on the long spur 1¾ miles north-northwest of the summit of Packard Peak, but such beds are either absent or concealed elsewhere in this part of the quadrangle. A thin quartzitic band, in nearly the same stratigraphic position, was also noted on the ridge south of the Scranton mine, in the North Tintic district.

LITHOLOGY.

The quartzite beds in the Tintic district proper are of light-yellowish to pale-brownish color on weathered surfaces and may have a very pale pink tinge on fresh fracture. They are mostly of fine, even-grained texture, but they include small quartzite pebbles an inch or more in diameter. On the application of dilute acid the rock shows slight to moderate effervescence. The quartzite pebbles may have been derived from Cambrian quartzite, but it is possible that, in part or wholly, they represent Ordovician or Silurian strata now completely eroded, as Ordovician quartzite is present in the northern Wasatch Mountains and the San Francisco district, and late Ordovician quartzite occurs in the Eureka district, Nevada.

The limestone ranges from fine and medium even grained to conglomeratic, and the coarser beds contain limestone pebbles as much as 2 inches in diameter. The pebbles are mostly of bluish-gray color, but their weathered surfaces are yellowish, pinkish, or reddish. Both pebbles and matrix are dolomitic, the matrix containing a varying amount of quartz grains. The pebbles for the most part are of the same general type as the Bluebell dolomite.

STRATIGRAPHIC POSITION.

Although no fossils have been found in this quartzitic zone, its presence at the base of the Mississippian limestone and the evidences, already cited, of an unconformity beneath it show that it is the basal formation of the Mississippian.

GARDNER DOLOMITE (LOWER MISSISSIPPIAN).

DISTRIBUTION AND THICKNESS.

The Gardner dolomite is recognized as a distinct formation because it contains a great variety of recognizable fossils, most of which were found on the spur west of Gardner Canyon. It is well exposed on the eastward-sloping spurs north of Packard Peak, but between that locality and Eureka Gulch it is mostly concealed and the thin strip shown on the map (Pl. IV) is recognizable principally because of its position east of the Victoria quartzite. From Eureka Gulch it extends southward to the slope below Mammoth Bluffs, where it is abruptly cut off by a strong zone of east-west faults. In the East Tintic district it is poorly exposed on the ridge south of Burriston Canyon. It also forms the summits and western slopes of Pinyon Peak and the hill immediately south.

The top of the formation is mapped at the base of the lowest exposed black cherty beds of the Pine Canyon limestone, but this is only an indefinite boundary where exposures are not continuous. A black shaly bed about 100 feet thick and at about the same horizon would be a better boundary marker, were it not so poorly exposed. Whether it lies below or above the lowest black cherty bed has not been determined, but its presence indicates approximately the top of the Gardner formation. The true thickness of the formation is not known, both because of the indefinite upper limit and because of flexures and faults which are known to exist but which are too obscure to be mapped accurately. The section measured by Tower and Smith during the first survey shows a thickness of only 435 feet between the Victoria quartzite and the lowest black cherty beds. This amount may be too small, owing to the possible elimination of a portion of the strata by concealed north-south

faulting. East of Eureka Peak, on the other hand, the apparent thickness is at least 800 feet, but this is evidently due in part to repetition by the Emerald-Grand Central fault, whose exact position at this place is concealed. The thickness exposed in the Yankee shaft is about 700 feet, but no beds corresponding to the Victoria beds have been cut here, and this amount must be considered only an approximation of the true thickness.

LITHOLOGY.

The greater part of the formation is fine-grained gray to dark bluish-gray dolomite containing an abundance of silicified fossils. Small chert nodules are present in some beds but are not especially conspicuous. Interstratified with the dolomites are a few beds of black dense carbonaceous limestone. East of the Victoria mine the rocks are much fractured and contain veinlets of white "sparry" dolomite. Both the dolomite and the limestone, when dissolved, leave an abundant residue of fine siliceous grains (mostly fossil remnants) and carbonaceous material. They leave an oily film on the surface of the solution and give a pronounced odor of hydrogen sulphide.

At or near the top of the formation is the bed of black highly carbonaceous and pyritic shaly limestone, mentioned above, which is about 100 feet thick. It is cut on the 500-foot levels of the Northern Spy and Iron Blossom No. 3 mines, the 900-foot level of the Beck Tunnel No. 2 shaft, and the 1,300-foot level of the Yankee shaft, but it is not well exposed at the surface and its exact stratigraphic position is not known. The top of this bed forms a watercourse in the Yankee mine. A similar but thinner bed is cut at the 1,800-foot level of the Yankee mine. These carbonaceous beds disintegrate readily and are likely to be covered by loose detritus or soil on the surface slopes.

CORRELATION.

Fossils in the Gardner dolomite have been found at four different localities and have been determined by G. H. Girty, of the United States Geological Survey, as follows:

Lot 1, from the flat spur on the west side of Gardner Canyon due west of the southwest summit of Godiva Mountain:

- Zaphrentis sp.
- Clisiophyllum sp.
- Crinoid stems.
- Crinoidal fragments.
- Camarotoechia sp.
- Spirifer centronatus.
- Spirifer sp.
- Syringopora surcularia?
- Composita humilis?
- Reticularia? sp.

Lot 2, from the southwest slope of Godiva Mountain below the trail:

- Zaphrentis.
- Syringopora surcularia.
- Composita humilis.

Lot 3, from the low knob about 4,500 feet N. 80° E. of the summit of Sioux Peak:

- Syringopora surcularia?
- Aulopora sp.
- Composita humilis.
- Euomphalus luxus.

Lot 4, from the top of the main east-west ridge due south of the Scranton mine, North Tintic district:

- Cystodictya sp.
- Chonetes illinoisensis.
- Cliothyridina aff. C. hirsuta.
- Conocardium sp.
- Euomphalus luxus.

Although most of the collections taken individually are almost too small to permit a satisfactory determination of their geologic age, yet taken together they indicate it with reasonable clearness. * * * Lots 1, 2, and 4, * * * which I understand were obtained from the same formation, give a combined fauna that can be recognized with some certainty as indicating the horizon of the Madison limestone. Similarly lot 3 shows pretty clearly the same facies, that of the Madison.

Comparison with Spurr's Mercur section[1] suggests the correlation of the black carbonaceous bed at Tintic with the upper black shale bed at Mercur, whose thickness is somewhat more than 100 feet, but it is by no means certain that a bed only 100 feet thick persists throughout the distance of about 30 miles between the Tintic and Mercur districts.

PINE CANYON LIMESTONE (LOWER AND UPPER MISSISSIPPIAN).

DISTRIBUTION AND THICKNESS.

The Pine Canyon limestone makes up the greater part of Godiva Mountain, Sioux Peak, and Mammoth Peak. It crops out continuously with steep or vertical dips from the north base of Godiva Mountain as far south as the east-west fault zone east of Mammoth, beyond which relative upward movement due to the fault and subsequent erosion have wholly removed it as well as the Gardner dolomite. In Pine Canyon, between Godiva Mountain and Sioux Peak, and again east of Mammoth Peak it can be followed eastward beneath the Humbug formation with flattening dip to and beyond the Eureka Hill Railroad, where it

[1] Spurr, J. E., op. cit., pp. 375, 377.

crosses the synclinal axis and is exposed continuously, with a gentle westerly dip, from the Yankee mine on the north to the Mammoth fault zone on the south. It is bounded on the north and east by the overlying volcanic rocks, except east of the Colorado mines, where the underlying Gardner dolomite is exposed. It also occurs extensively in the northern part of the quadrangle from the spurs west of Fremont Canyon eastward to the summit of Pinyon Peak.

Its thickness, like that of the Gardner dolomite, can not be accurately determined, but estimates based on the sections in the Beck tunnel No. 2 and Yankee shafts give about 1,000 feet.

LITHOLOGY.

There are two principal varieties which alternate irregularly throughout. One is a nearly black, dense, rather thin-bedded limestone containing large nodules of black chert, many nearly a foot in diameter, and a few thin beds of black chert. The largest nodules are found along the top and west slope of Godiva Mountain, especially the southwest summit. The base of the formation is drawn along the lowest exposed cherty bed, but it is not certain that the lowest bed of all is everywhere exposed. The cherty beds break up on weathering into angular blocks of varying size.

The other variety, which is economically the more interesting, is most conspicuous in the upper beds. It is of medium to light gray color, medium to rather coarse grain, and distinctly cross-bedded. Cross-bedding is especially distinct in the walls of Pine Canyon along the wagon road. The rock is a nearly pure limestone, dissolving rapidly in cold dilute hydrochloric acid and leaving practically no residue. An analysis, quoted from the earlier report,[1] is as follows: SiO_2, 0.57; Fe_2O_3, 0.90; CaO, 55.22; MgO, 0.41; CO_2 (calculated), 43.84; total 100.94 per cent. Small fragments of fossils are abundant in it and as a rule are easily detected. The ore bodies of the "Colorado channel" and of the Uncle Sam, Yankee, and May Day mines have been formed by the replacement of a bed (or beds) of this variety.

Besides those two varieties there are intermediate phases, such as black noncherty beds, cherty coarse-grained beds, and fine-grained light-gray beds.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 625.

CORRELATION.

Poorly preserved fragments of fossils, mostly *Zaphrentis*, are scattered through the cherty beds, but none of certain stratigraphic value were found. The fragments in the coarse-grained limestone are mostly not determinable, but two species from lot 121 were determined by Mr. Girty as *Zaphrentis* sp. and *Batostomella?* sp. Mr. Girty states that this lot, though representing very few species, appears to show a different fauna from the Madison, and he refers it tentatively to the upper Mississippian. These meager data are supported by more substantial evidence in the southern Wasatch Mountains just east of Santaquin, 20 miles northeast of the Tintic district, where in a section of the same lithologic character an abundant fauna, collected by the writer in in 1912 and determined by Mr. Girty, makes it possible to correlate the greater part of the cherty beds definitely with the Madison limestone, and the upper part, including the coarse-grained limestone beds, tentatively with the upper Mississippian. According to this evidence, the lower and perhaps the greater part of the Pine Canyon limestone is of Madison age, but at least the upper 300 feet is tentatively regarded as upper Mississippian. It is not possible to separate the beds assignable to these two horizons in the field, because of the scarcity of determinable fossils and the abundance of cherty beds alternating with and overlying the coarse-grained beds and persisting even in the overlying Humbug formation.

HUMBUG FORMATION (UPPER MISSISSIPPIAN).

The Humbug formation, which consists of alternating sandstone, shale, and limestone, is limited to the east slopes of Godiva Mountain and Sioux Peak and to three small areas near the north edge of the Tintic quadrangle (Pl. I) east and west of Fremont Canyon. The following section, shows its thickness and alternations:[2]

Section of Humbug formation on east slope of Sioux Peak.

Brown quartzitic sandstone	12
Black fossiliferous limestone	25
Brown sandstone	5
Blue limestone	4
Brown sandstone, in part quartzitic	90
Bluish-gray limestone	3
Sandstone and limestone	50
Reddish sandstone	25
Gray sandy limestone	6
Sandstone	¾
Light-brown sandy shale	30
	250¾

[2] Idem., p. 626.

The different members are intercalated lenses and the succession and thicknesses on Godiva Mountain are much different from those shown in the above section. The base is definitely drawn only where the lowest sandy or shaly beds are exposed. Some limestone members near the base may closely resemble beds of the underlying Pine Canyon limestone, and the boundary may easily be wrongly located where the bottom sandy or shaly bed is concealed. The higher limestone beds are dark blue to black and very fine grained to dense. The sandstones are greenish in color, weathering brown, and consist of rounded quartz grains cemented by calcite. Fossils especially fragments of *Zaphrentis* and of crinoid stems, are numerous.

The 250 feet of strata form but the lowest part of an extensive formation represented at Mercur by the "upper intercalated series" 5,000 to 6,000 feet thick, the upper part of which, at least, is of Pennsylvanian age.[1] The lower portions, however, and perhaps the greater part of this formation carries upper Mississippian fossils (collected by the writer in 1912 and determined by G. H. Girty) in the Lake Mountains, west of Lehi and 30 miles north-northeast of the Tintic district, and in the Wasatch Mountains, southeast of the Cottonwood district. The "intercalated series" thus appears to mark a transition from late Mississippian to early Pennsylvanian time,[2] and the Humbug formation, which represents its basal beds in the Tintic district, is therefore to be assigned to the upper Mississippian.

IGNEOUS ROCKS.

GENERAL FEATURES.

The greater part of the Tintic quadrangle (see Pl. I, in pocket) is covered by igneous rocks. These are mostly effusive but include a few necks or stocks and dikes. They consist for the most part of rhyolite, monzonite, latites, and perhaps andesites, with minor quantities of basalt. The order of eruption is not perfectly known, for during neither the first nor the second survey was there sufficient time for a thorough study of this problem, the solution of which would require considerable investigation of areas remote from the mining districts of the Tintic quadrangle. The present writer's study beyond the limits of the mining district was confined to three reconnaissance trips—one southward to Sunrise Peak and Volcano Ridge, one eastward along the northern edge of the main latite-andesite area, and one along the rhyolite-latite contact southeast of Homansville Canyon. The evidence found on these trips accords closely in all essential points with the conclusions published in the earlier report, and the only noticeable difference is that it affords data for a somewhat more detailed mapping in certain places and for the recognition of an earlier and later series of andesitic flows. The sequence of eruptions, so far as known, is as follows: Early latite or andesite, rhyolites, main latite-andesite group and monzonite, basalt.

The gentle dips of the flows and their contacts with eroded or even talus-covered sedimentary rocks show that the eruptions took place long after the sedimentary rocks had been folded, faulted, and eroded into topographic forms much like those of to-day. Some extensive faulting, however, synchronous with that which developed the Basin Ranges, took place after the eruptions.

EARLIER BIOTITE-AUGITE LATITE OR ANDESITE.

Although no well-defined outcrop of andesitic rock older than the rhyolite has been found, the existence of such a rock has been proved by microscopic study. Specimens of this rock were found on the dump of the Crown Point shaft, east of the Eureka Hill Railroad, near the head of the gulch which marks the south boundary of the silicified fluidal rhyolite. The shaft evidently passes through the rhyolite into the andesitic rock. Inclusions identical in microscopic character with the andesitic rock are present in the rhyolite, thus proving the existence of a prerhyolite andesite or latite.

Exposures of highly altered lava that probably belong to this earlier andesitic flow have been noted beneath the rhyolitic tuff at the head of Ruby Canyon and beneath the Packard

[1] Spurr, J. E., op. cit., p. 377.

[2] Blackwelder has found an unconformity between the Mississippian limestone and the overlying Pennsylvanian formation ("red beds near Morgan") in the upper canyon of Weber River, but concludes (New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, p. 530, 1910) that the erosion interval must have been geologically brief, for fossils from beds above and below the unconformity have been determined by Mr. Girty as early Pennsylvanian. No corresponding unconformity has yet been reported west or south of this locality.

rhyolite, a mile farther north, at the bend in Burriston Canyon. The rock in these exposures appears to have been originally an andesite or latite but is now too thoroughly bleached by sericitization and kaolinization to be more definitely determined.

The rock has a dark-purplish to nearly black color, weathering to pale pinkish, a dense, finely porphyritic texture, and a fine fluidal structure so like that of the fluidal rhyolite that in the field the two rocks were believed to be the same. The visible minerals are plagioclase in lath-shaped crystals, 2 to 4 millimeters long, with prominent twinning striations, and biotite in minute, poorly defined flakes. Small cavities mark the former presence of another mineral which the microscope proves to have been augite altered largely to calcite. A little secondary quartz is present along the flow lines.

In the one thin section studied the flow structure is not noticeable except around the phenocrysts. The plagioclase is zonal and shows both Carlsbad and albite twinning. Extinction angles in sections normal to the twinning plane indicate an average composition near $Ab_{30-35}An_{70-65}$. The extinction angle on a 010 section indicates a composition for the innermost zone of $Ab_{20}An_{80}$. The crystals as a whole are very free from alteration, but a few have gone slightly to calcite and sericite. The biotite forms automorphic crystals about 1 millimeter long showing dark reddish-brown to nearly white pleochroism. Basal sections are distinctly marked by needles of sagenite (rutile). Some crystals are altered slightly to a fine chloritic aggregate (delessite?), and all have altered to limonite along their edges. The augite is nearly all altered to pseudomorphs of calcite with more or less chlorite, but enough is left to prove its identity. The original mineral formed short automorphic prisms from less than 1 to about 2 millimeters long. Magnetite and apatite are prominent as microphenocrysts, especially within and close to the augite crystals. The magnetite grains range from mere specks to irregular grains nearly 1 millimeter in diameter. Some of the larger grains appear like accretions of several small grains and poikilitically inclose apatite, small plagioclase laths, and small patches of groundmass. The groundmass is composed of minute feldspar laths, fine granules of the mafic minerals and their alteration products, and probably a little glass. Some of the distinct plagioclase laths are poikilitically embedded in material of slightly lower birefringence and no definite crystal outline, which appears like orthoclase. The extreme fineness of the groundmass prevents any estimate of the relative quantity of the two feldspars, and it is not known whether the rock contains enough orthoclase to be classed as a latite.

RHYOLITES.

SUBDIVISIONS.

Three large areas of effusive rhyolite and one of intrusive rhyolite were mapped during the earlier survey. The southernmost effusive body, called the Fernow rhyolite, lies mostly to the south of the Tintic quadrangle, but its north edge is 1½ miles north of the southern boundary, and scattered outliers are mapped as far north as Volcano Ridge. (See Pl. I.) The northernmost body, to which no specific name was given, lies north of the quadrangle, except for a narrow prong at the northeast base of Pinyon Peak. These two bodies of rhyolite were not studied during the recent survey.

The other effusive body, called the Packard rhyolite, and the intrusive body, designated the Swansea rhyolite, are described below in detail. Besides these, two minor occurrences of rhyolite, designated earlier rhyolite and rhyolite of Tintic Mountain, and one of rhyolite tuff have been distinguished. As the earlier rhyolite and the tuff are older than the Packard rhyolite their descriptions are given first.

EARLIER RHYOLITE.

DISTRIBUTION AND STRUCTURAL RELATIONS.

The earlier rhyolite, a silicified rock of fluidal structure, has been found at two places—on the broad, low spur sloping eastward from the east base of Mammoth Peak and near the north end of the main latite-andesite ridge, about 2 miles farther east. The only other evidence of earlier rhyolite is a thin section cut from a specimen collected west of Tintic Mountain during the earlier survey. In the spur east of Mammoth Peak the rock is well exposed along and just below the Eureka Hill Railroad, across the draw from the Iron Blossom No. 3 mine. Here its flow lines dip gently eastward. The greater part

of the spur is covered only by float, the identity of most of which is obscured or destroyed by bleaching, but recognizable specimens are scattered over the whole area. The boundary of the earlier rhyolite is therefore only approximate. At its west end the rock overlies limestone and is overlain by isolated patches of rhyolitic tuff and Packard rhyolite; to the east it appears to dip beneath the same rocks, but the structure is obscured by the presence of monzonite porphyry of doubtful occurrence.

The other body of the earlier rhyolite lies south of the East Tintic Cambrian limestone area. It has not been mapped in detail but has been found to underlie the rhyolitic tuff and Packard rhyolite at the two places where the base of the Packard is exposed—one at the easternmost outcrop on the crest of the ridge and the other close by the Silver Pass road at the west base of the ridge. This relation, together with the petrographic character of the rock, justifies its correlation with the rhyolite just described. The distribution of outcrops of the earlier rhyolite and still more of the Packard rhyolite proves the existence of several faults in steplike arrangement from the Silver Pass road eastward. The relative downward movement in each fault has been on the west side, except along the easternmost fault found. Here the east wall has moved relatively downward, cutting off the rhyolites. This fault is the strongest evidence of post-volcanic faulting yet found in the Tintic quadrangle and has produced a local development of "Basin Range structure."

LITHOLOGY.

The freshest material found is of a medium brown color, which grades toward purple and pink. Where the rock is completely altered by silicification and kaolinization it is bleached to a white color more or less streaked by rusty stains. Its texture is dense and slightly to moderately porphyritic, but its most striking feature is the persistent fine flow structure marked by short dark undulating streaks. The visible minerals are altered feldspar and biotite, in crystals averaging about 2 millimeters in diameter, and secondary chalcedony, or opal, which has been deposited along flow lines and which has partly replaced some of the feldspars.

In thin section the rock is principally a brown glass streaked by small aggregates and wavy veinlets of chalcedonic quartz, highly altered phenocrysts of feldspar and biotite, and inclusions of latite or andesite. The feldspar phenocrysts consist of oligoclase and sodic sanidine, though most of them are too thoroughly altered to be properly identified. No quartz phenocrysts were noted. The biotite is so much altered that hardly a grain retains its original character. Magnetite and apatite are present, the latter in typical well-formed prisms as much as 0.5 millimeter long.

The alteration products, besides chalcedonic quartz, are sericite, chlorite in very fine radiating aggregates, a little magnetite or specular hematite, and more or less kaolin and limonite. The chalcedonic quartz, in veinlets and microgeodes, occurs alone in and also intermixed with the other secondary minerals. Sericite with chalcedony and a small amount of chlorite replace the feldspars. Chalcedony, chlorite, and magnetite or specularite in varying quantities replace the biotite. Kaolin and limonite occur in the altered feldspar and biotite respectively.

RHYOLITIC TUFF.

Volcanic tuff containing quartz is found both below and above the Packard rhyolite. Only that below the rhyolite is described under the above heading. The upper tuff is described on pages 54–56 under the heading "Latite tuff."

The rhyolitic tuff has been found in scattered localities east of Knightville, east and southeast of Mammoth Peak, and farther east, where it overlies the earlier rhyolite. At every place except the southernmost it underlies the Packard rhyolite, being exposed only where the rhyolite has been completely removed by erosion, but at no place has the whole extent of an exposure been mapped. The southernmost exposure, at Sioux Pass, is thoroughly bleached and so confused with bleached spherulitic and porphyritic rock, the latter apparently latite or monzonite porphyry, that its structural relations can not be definitely determined. On the south slope of this spur, at the southernmost limit of the Bluebell dolomite, a little float of bleached tuff was found, indicating a former extension farther south.

The freshest material, found above the easternmost occurrence of earlier rhyolite, is of brownish color and fine to rather coarse grain.

and is composed of distinct grains of feldspar, quartz, and biotite and fragments of glassy rhyolitic and latitic groundmass. Most of the exposures, however, are greenish owing to partial alteration or bleached to white by silicification followed by kaolinization. In the bleached material quartz in scattered granules is the only recognizable mineral other than kaolin. The bleached tuff is well exposed in the railroad cut east of the Iron Blossom No. 3 mine.

PACKARD RHYOLITE (TOSCANOSE).

DISTRIBUTION AND STRUCTURAL RELATIONS.

The Packard rhyolite covers an area of 18 to 20 square miles north and east of Eureka. Its boundary is very irregular, owing largely to the irregularity of the surface of the eroded underlying limestone and in the eastern part to the incomplete removal of the overlying andesites. Its westernmost extremity, at Hatfield Canyon, clearly overlies the limestone, and the neighboring small and thin outliers are probably remnants of a once greater mass. At Packard Peak, less than a mile to the east, the rhyolite is from 800 to 1,000 feet thick (see Pl. VIII, *A*, p. 18, and Pl. II, section A–A′, in pocket) and is of very uniform texture, the only irregularities noted being a few small inclusions of bleached rhyolitic tuff a few inches in diameter. This great thickness and the uniformity of character suggest strongly, as stated in the earlier report, that the center of eruption underlies Packard Peak and the ridge just east of it. The following paragraph is quoted from the earlier report:[1]

> The absence of any bedded structure in the central portion of the area and the great thickness of the rhyolite in the vicinity of Packard Peak suggest that this is the center of an eruption which was of the nature of an outwelling of viscous lava, rather than of an explosive ejection of volcanic material. Very little truly fragmental material is found in association with these rhyolitic flows, yet much of the rhyolite shows traces of flow brecciation, such as might be expected to occur in the eruption of a highly viscous lava.

The fact that a few small rhyolite dikes that cut limestone in the upper part of the Jenny Lind Canyon and also in the Gemini mine trend toward Packard Peak lends a little further weight to this conclusion, which is illustrated in section A–A, Plate II, drawn southeastward through Packard Peak.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., pp. 651-652.

Other small dikes poorly exposed have been noted at a few places on the surface and in mines. Some of these dikes, especially those in the vicinity of Pinyon Peak, are closely associated with outcrops of opaline or chalcedonic silica replacing limestone and may have a genetic connection with them. If so, these siliceous deposits are older than those that accompany the ore deposits, which were formed after the monzonite intrusion.

South of Packard Peak the rhyolite lies against a steep erosion slope of limestone. The contact has been exposed in the workings of the Gemini mine, where the rhyolite covers a steep talus slope. Wells and mine workings prove the rhyolite to underlie the thick covering of alluvial soil beneath Eureka. The shaft of the Chief Consolidated mine passes through 300 feet of alluvium and rhyolite into underlying limestone. The contact of rhyolite and limestone again comes to the surface at the north base of Godiva Mountain. The rhyolite here also flanks an erosion slope of limestone, and exposures in the Tetro tunnel workings show the rhyolite overlying limestone talus. The contact continues southeastward at about the 7,000-foot contour around Godiva Mountain to a point beyond the Yankee mine. South of this point more pronounced erosion has removed it and exposed the underlying limestone slope as low as the 6,600-foot contour. A few remnants of the rhyolite at Pine Canyon, east of the Northern Spy mine, and possibly at Sioux Pass mark its former southward extent, and smaller remnants, mostly represented only by float, occur farther east.

The relations between the Packard rhyolite and the flows of latite (and andesite?) to the south of it are obscure, as nearly the entire surface is covered by débris. It may be that the southward-thinning end of the rhyolite originally crossed the present eastward-sloping canyon (Pl. I) and passed beneath the latite, but no trace of rhyolite south of this canyon could be found at the appropriate horizon along the east slope of Ruby Canyon (Pl. IV); or possibly faulting along both of the canyons has buried any southward extension of the rhyolite, but no positive evidence of faulting could be found to warrant even approximate mapping. For want of better evidence it is concluded that only a very thin tapering edge

of the rhyolite flow, now wholly concealed beneath latite débris, could have extended southward beneath the present north boundary of the latite flows.

Along the eastern boundary of the Packard rhyolite area the uppermost portion of the rock, consisting largely of obsidian, dips gently beneath a considerable thickness of latitic or andesitic tuff and breccia, which in turn is covered by one or more latite flows. It is therefore certain that although some of the latite or andesite flows (p. 42) are older than the Packard rhyolite, most of them, to judge from the map (Pl. I) and from evidence presented elsewhere (pp. 54–56), are younger. In the step-faulted area east of the Silver Pass road (p. 89) the rhyolite is also overlain by latite.

The present and original thicknesses of the Packard rhyolite are shown approximately in section A–A′, Plate II. The greatest known thickness at any point except Packard Peak is at the 7,007-foot peak a mile east of Knightville. (See Pls. I and IX, *B*.) A shaft on the flank of this peak, about 500 feet below the summit, is said to have reached limestone at a depth of 50 feet, giving a total thickness here of about 550 feet. The difference in elevation between the summit and the lowest outcrop in the valley directly to the east shows that the original thickness of the rhyolite over the canyons in this vicinity must have been 1,000 feet, with no allowance for erosion at the peak's summit. If little or no allowance is made for the northward continuation of the faults indicated in the main latite ridge to the south, a slope of 7° (about 650 feet to the mile) from the latite and rhyolite contact would pass well above the summit of the 7,007-foot peak and between 800 and 1,000 feet above the summit of Packard Peak. As these faults, if present, tend to compensate one another, the above figures may still serve as a rough estimate of the original thickness of the Packard rhyolite.

Proof of an original surface slope of 7° or even less would verify the conclusion that the Packard rhyolite never extended southward for any considerable distance beyond the present northern boundary of the great latite-andesite area. It hardly seems probable, therefore, that there was any surface connection between the Packard rhyolite and the Fernow rhyolite in the southern part of the quadrangle. On the other hand, this conclusion would imply that the rhyolite flow (or flows) once nearly or quite covered the quartzite and limestone ridges in the northwest corner of the quadrangle and connected west of Pinyon Peak with the northern rhyolite area mentioned on page 43.

LITHOLOGY.

The Packard rhyolite presents many variations in appearance but is distinguished from all the other volcanic rocks here described (except the Swansea rhyolite) by the presence of quartz phenocrysts. Its prevailing color is pink, but gray, brown, and dark purple are prominent locally, and the purple tints make the rhyolite resemble some members of the latite-andesite series. Glassy phases of the rhyolite are gray to black. Sericitic alteration produces a pale-greenish color, which by weathering may bleach to a pure white. Where disseminated pyrite has begun to weather a characteristic greenish-yellow color results. This color is well shown on the various small dumps around the Denver & Rio Grande Railroad wells north and northeast of Eureka. The texture is uniformly porphyritic, and the phenocrysts constitute about 20 per cent of the rock. The groundmass is usually dense, but at the upper contact with the latite-andesite series and at a few places within the rhyolite area, it is typical obsidian, mostly massive, but in a few places, at the very top, scoriaceous. The obsidian, which is most readily seen along the railroad between Eureka and Homansville, indicates several successive flows of rhyolite, but no attempt was made to ascertain the number of flows.

The most conspicuous major structural features are the breccia and the platy parting or flow structure. The brecciated structure is confined, so far as seen, to the base of the rhyolite. It is well exposed along the railroad cut east of the Northern Spy shaft and has also been found near the mouth of Burriston Canyon and in the exposures in the faulted area east of the Silver Pass road. The rock is evidently a flow breccia, caused by the fracturing of partly hardened lava while it was still flowing, and consists of fragments of light-colored

rhyolite porphyry in a darker matrix of the same composition. The platy flow structure is a very prominent feature of the larger outcrops and is especially well shown southeast of Packard Peak and in the knobs north of the lower road fork of Goshen Slope. The platy partings as a whole dip rather gently away from Packard Peak but are modified by numerous contortions where the dip is locally steep, vertical, or even reversed. They have been largely influential in promoting a rapid disintegration of the rhyolite and also afforded openings for permeation by mineralizing solutions or vapors. Calcite, opaline and chalcedonic silica, and heulandite have been found in the partings. The heulandite is best developed in small pockets that are local enlargements of the platy partings or of other fractures.

The visible minerals are feldspar, quartz, and biotite. Both orthoclase and plagioclase feldspars are present, but in general it is very difficult to distinguish them, for both are glassy where fresh, are of tabular habit, and break mostly across the basal cleavage, so that the presence or absence of plagioclase twinning striations can not be proved. The feldspar crystals occur as single or simply twinned tabular crystals as much as 4 millimeters long, also as small aggregates of nearly parallel crystals that appear at first glance like broad, nearly cubic grains complexly twinned. Quartz appears in small rounded grains, or here and there as nearly perfect bipyramids, mostly less than 2 millimeters in diameter. It is distinctly less abundant than the feldspar but is easily recognized, both in the fresh and in the thoroughly altered rock, and is, as already stated, the distinguishing feature of the Packard rhyolite among the effusive rocks of the district. Its clear, highly glassy single grains are readily distinguishable from minute druses and cavity fillings of secondary chalcedonic quartz and opal, which are less glassy in luster, are nearly or quite opaque, and have irregular outlines. The biotite, as in all the other volcanic rocks of the district, forms typical black shiny 6-sided tablets 2 or 3 millimeters in diameter and of almost perfect outline. A few grains are altered to a green chloritic mineral, and several have weathered to different shades of brown.

In most thin sections a distinct flow structure is noticeable around the phenocrysts, many of which have been broken and the fragments separated. All the larger phenocrysts, feldspar, quartz, and biotite, show considerable fracturing and resorption, which in some sections are so pronounced that, except where differences in composition could be determined, it would be difficult if not impossible to distinguish the rhyolite phenocrysts from inclosed fragments of phenocrysts from the older volcanic rocks.

Plagioclase is surprisingly abundant in view of the difficulty of identifying it megascopically. Many of its grains have a marked zonal structure. Both Carlsbad and albite twinning are common, and pericline twinning is often seen. Extinction angles on sections showing both Carlsbad and albite twinning indicate an average composition of andesine near $Ab_{65}An_{35}$. The most calcic zone measured showed $Ab_{40}An_{60}$. A few crystals appeared to be in all zones less sodic than $Ab_{60}An_{40}$, but most were $Ab_{65}An_{35}$ or even more sodic.

The sanidine phenocrysts are much less abundant than those of plagioclase. Their character varies considerably. A simple, clear Carlsbad twin, more or less resorbed, was found in only one of 17 sections. Irregular perthitic intergrowth with albite is common in independent twinned crystals and also in partial outer borders around plagioclase. Extinction angles on 010 measure 8° to 10°, figures which, together with the perthitic structure, indicate a high soda content. In view of the composition and relatively small quantity of the sanidine phenocrysts the high potash content in the chemical analysis implies that sanidine or its uncrystallized constituents must constitute a considerable part of the groundmass.

Quartz occurs in rounded and irregular grains that are considerably resorbed, but a few still show the original bipyramidal outline. Several grains are fractured. Some are surrounded by a fringe of small radiating quartz crystals, which may be explained by the fact that the quartz phenocrysts, formed prior to eruption, were partly resorbed during eruption and finally, when the erupted lava solidified, were coated by the fringe of rapidly crystallizing quartz from the groundmass. Aggregates of the small radiating crystals are also found without the nucleus and suggest that

even after eruption quartz molecules had begun to segregate but were forced to crystallize too rapidly to form single phenocrysts; however, these aggregates may also be explained as recrystallizations of wholly resorbed phenocrysts, or perhaps only the fringe and not the central part of the phenocryst was included within the thin section.

Biotite, in unaltered crystals, shows typical absorption. Some of the crystals are marked with rutile in sagenite twins. Unaltered grains are marked by narrow resorption rims specked with magnetite. In most sections, however, biotite is more or less replaced, locally, by chlorite with sericite, calcite, and silica but generally by limonite, which may totally obscure any other alteration products. Brown hornblende is seen in a very few sections. Magnetite and a little apatite and zircon form typical microphenocrysts scattered through the groundmass but more conspicuous within or around biotite phenocrysts. The groundmass ranges from a clear glass to material that is completely microcrystalline. The glass has usually a flow structure marked by numerous hairlike crystallites, and some of it is minutely spherulitic. The completely microcrystalline texture is quite like that of the intrusive Swansea rhyolite. Short, stout lath-shaped crystals of plagioclase are present but appear subordinate to the anhedral and poorly defined granules of alkalic feldspar and quartz.

Alteration has produced varying results according to its intensity: where it was less pronounced plagioclase is partly changed to sericite and calcite with a little chalcedonic silica, and biotite to chlorite (delessite?), whereas sanidine and quartz remain unchanged; where it was more pronounced chalcedonic silica has increased at the expense of all the other minerals, both primary and secondary, except quartz, and may be accompanied by a small amount of fine pyrite grains. Thoroughly altered rock is composed of chalcedonic silica with a little sericite and pyrite. Where flow structure is pronounced the microscopic flow partings are partly or completely filled with silica ranging from opal through chalcedony to typical quartz. Tridymite is also present in similar occurrences.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical analysis in column 1 of the following table represents a gray porphyritic variety of the rhyolite occurring south of Pinyon Creek. The megascopic minerals are sanidine, rather acidic plagioclase, quartz, biotite, and a little hornblende; the microscopic minerals are tridymite, magnetite, apatite, and zircon in a groundmass that is for the most part crystalline but contains a small amount of glassy residue.

The prominence of quartz and sanidine phenocrysts is sufficient to classify the rock in the field as rhyolite, and comparison of the analysis with those in columns 2, 3, 4, and 5 shows the Packard rhyolite to be very similar to certain other rhyolites and dacites in neighboring States. It differs, however, from the average rhyolite (column 6) in its lower content of SiO_2 and higher MgO, CaO, K_2O, TiO_2, and P_2O_5. These differences indicate that it approaches quartz syenite and especially monzonite, as shown by comparison with analyses in Washington's Tables [1] and with the analysis of the local monzonite given on page 67. The monzonitic character is further indicated by the compositions and ratio of the feldspars. If the modal plagioclase, as determined optically, is subtracted from the norm (p. 71), the ratio will be approximately alkalic feldspar ($Or_{74}Ab_{26}$) 35 per cent and plagioclase ($Ab_{65}An_{35}$) 29 per cent (allowance being made for 6 per cent biotite). According to the norm the rock falls well within the coordinates I.4.2.3 and is a toscanose.

[1] Washington, H. S., Chemical analyses of igneous rocks published from 1884 to 1913: U. S. Geol. Survey Prof. Paper 99, pp. 165-217, 1917.

Analyses of Packard rhyolite and similar rocks.

	1		2	3	4	5	6
	Analysis.	Molecular ratio.					
SiO_2	69.18	1.153	69.96	70.87	69.45	69.95	72.60
Al_2O_3	14.37	.141	15.87	15.18	14.92	15.14	13.88
Fe_2O_3	2.52	.016	2.50	2.18	3.16	.38	1.43
FeO	.57	.008	Undet.	.12	.23	.83	.82
MgO	.70	.018	.64	.60	.05	.56	.38
CaO	1.88	.034	1.73	1.58	1.19	1.45	1.32
Na_2O	3.58	.058	3.80	3.47	3.19	2.70	3.54
K_2O	5.00	.053	4.12	5.01	5.95	6.36	4.03
H_2O-	.35	....	....	....	....	.40	....
H_2O+	.25	....	1.53	1.08	1.69	.91	1.52
CO_2	Undet.	....	....	....	....	.37	....
TiO_2	.69	.009	....	Trace.	.19	.24	.30
ZrO_2	Undet.	....	....	....	....	....	....
P_2O_5	.26	.002	....	Trace.	.06	.10	.06
SO_3	Undet.	....	....	....	....	....	....
Cl	Trace.	....	....	....	....	....	....
Cr_2O_3	Trace.	....	....	....	....	....	....
MnO	.10	.001	....	Trace.	.07	.08	.12
BaO	.09	.001	....	....	.03	.13	....
SrO	Trace.	....	....	....	....	....	....
Li_2O	Trace.	....	....	....	....	....	....
V as V_2O_3	.01	.000	....	....	....	....	....
Mo	Trace.	....	....	....	....	....	....
	99.55	....	100.7	100.12	100.18	100.06	100.00

1. Packard rhyolite, south of Pinyon Creek, Tintic mining district, Utah. H. N. Stokes, analyst. Tower, G. W., jr., and Smith, G. O., op. cit., pp. 634–635.
2. Dacite, McClellan Peak, Washoe, Nev. F. A. Gooch, analyst. U. S. Geol. Survey Bull. 17, p. 33, 1885.
3. Rhyolite, Pennsylvania Hill, Rosita Hills, Colo. L. G. Eakins, analyst. U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 324, 1896.
4. Rhyolite, Sunset Peak, Bear Gulch, Yellowstone National Park. L. G. Eakins, analyst. U. S. Geol. Survey Mon. 32, p. 325, 1899.
5. Quartz porphyry, Modoc mine, Butte district, Mont. W. F. Hillebrand, analyst. U. S. Geol. Survey Bull. 168, p. 119, 1900.
6. Average of 64 analyses of liparite and rhyolite. R. A. Daly, compiler. Am. Acad. Arts and Sci. Proc., vol. 45, p. 219, 1910.

SWANSEA RHYOLITE (TOSCANOSE).

DISTRIBUTION AND STRUCTURAL RELATIONS.

The Swansea rhyolite forms one main mass nearly three-fifths of a mile long and averaging a quarter of a mile wide between Robinson and Silver City and a smaller mass occupying the greater part of the 6,640-foot hill just southeast of Robinson. The only other known natural exposures are a thoroughly decomposed dike of northeasterly trend on Quartzite Ridge, and a small isolated, badly weathered outcrop in the monzonite area about a mile east of Silver City. Other dikes of rhyolite of northerly to northeasterly trend have been exposed in the deeper workings of the Opex, Centennial, Eureka, Gemini, and May Day mines. The Swansea rhyolite is clearly intrusive in the sedimentary rocks. Nearly vertical contacts with the quartzite are exposed at the northwest corner of the main mass, where the contact dips 80° W., and along the decomposed dike on Quartzite Ridge; and similar contacts with the limestone may be seen southeast of Robinson and along the dikes in the different mines.

The dikes in the mines are of interest in that they represent the upper terminations of intrusive bodies. Those in the Opex and Centennial Eureka are regular dikes or pod-shaped or flat masses, in places with a strong southerly pitch and pinching out toward the north. (See fig. 13, p. 82.) That in the May Day is of similar shape but has a northerly pitch. They show, where not too decomposed for study, chilled margins characterized by a less porphyritic texture than the rest of the rock.

The contact between the main mass of the Swansea rhyolite and the adjacent monzonite is not satisfactorily exposed, being for the most

part marked only by loose fragments. (See Pl. X, *B*.) Only in the saddle half a mile due north of the Swansea shaft is it at all well shown. Here the two rocks are somewhat dovetailed together. A few short dikelike masses of monzonite occur within the rhyolite, but none can be followed more than 3 or 4 yards and none can be proved to connect with the main body of monzonite. They may easily be regarded as inclusions on the evidence at hand. The only indication in them of dikelike character is the approximately parallel positions of opposite sides, but these can not be followed together more than 3 or 4 feet. The absence of any pronounced evidence of chilling of the monzonite at the contact and its more granular texture than that of the rhyolite may be regarded as suggestions, though by no means proofs, that the monzonite is the older rock; but no unbiased observer can draw a conclusion from the evidence at this point. The exposed contact is also somewhat irregular due east of the Swansea shaft, but here again the evidence is quite inconclusive. The Swansea shaft crosses the contact near the 900-foot level, where the monzonite dips about 60° W. This relation, together with the stocklike character of the monzonite body, may favor slightly the conclusion that the monzonite is the younger rock. The best evidence, however, is the rhyolite inclusion close to two larger inclusions of quartzite in the monzonite east of Silver City. No stringers of monzonite could be found in the rhyolite, but its blocky form and its close association with the undoubted inclusions of quartzite can hardly favor any other interpretation than that it too is an inclusion.

The balance of evidence, then, points to the rhyolite as the earlier of the two rocks; but the absence along its edge of chilled monzonite contacts such as are found along the limestone shows that the rhyolite, though consolidated, was still at a very high temperature when the monzonite was intruded. The triangular quartzite inclusion in monzonite in the saddle west of the Robinson triangulation station is surrounded by a narrow border of quartz porphyry very similar to but not identical with the Swansea rhyolite in megascopic as well as microscopic appearance. It grades into typical monzonite and seems best interpreted as due to marginal assimilation. This relation, while hardly applicable to so large a mass as the Swansea rhyolite body, is nevertheless further suggestive of close connection between the rhyolite and the monzonite.

LITHOLOGY.

The Swansea rhyolite is dark gray or greenish gray where quite unaffected by weathering or by intense silicification, but its prevailing color is pale pink, which by prolonged weathering gradually bleaches to light gray or white more or less streaked with rusty stains. It is of dense to very fine grained porphyritic texture, and some specimens of it may be confused with some of the Packard rhyolite; but it is as a whole more highly porphyritic, has a more thoroughly crystallized groundmass, is not glassy, and nowhere shows any of the pronounced brecciation or flow structure so characteristic of the Packard rhyolite. In some places the groundmass is sufficiently crystalline for the rock to be called a granite porphyry. The recognizable phenocrysts, which form about 30 per cent of the rock, are feldspars, quartz, and the remains of thoroughly altered biotite. The only distinct megascopic feldspar is the alkalic, which occurs in roughly rectangular crystals that average 3 millimeters in length and are mostly of pale pink color. They are hardly transparent enough to be called sanidine, and under a lens many of them show a distinct perthitic structure. Plagioclase, though abundant, is too obscured by alteration to be certainly identified megascopically. Its crystals are rather dull white, are of poorly defined shape, and only rarely show cleavage surfaces. Quartz is very prominent, mostly in colorless to smoky-gray rounded glassy grains as much as 2 or even 4 millimeters in diameter, with a few well-formed bipyramids. Altered biotite (determined only microscopically) is represented by dark-green spots of chlorite and clusters of minute black granules of magnetite in various proportions.

The groundmass and to a slight extent some of the phenocrysts are at many places impregnated with minute grains of pyrite, which may appear in slightly altered (greenish) or in thoroughly silicified (hard whitish) rock. Pyrite is especially prominent in the rhyolite dikes exposed in the Opex and Centennial Eureka mines. These dikes are remarkably soft but retain all their textural features. Other dikes—for example, those in the Gemini

mine—are thoroughly kaolinized, and their advanced stage of alteration may have been due largely to sulphuric acid derived from oxidizing pyrite.

In thin section the texture is finely granular porphyritic. The alkalic feldspar in hypautomorphic phenocrysts is microperthite, in part fresh, in part greatly kaolinized. It incloses grains of all the other minerals. Plagioclase phenocrysts are less abundant than those of alkalic feldspars. They also are hypautomorphic, and most of them are largely altered to sericite and kaolin. The only grains suitable for measuring extinction angles (on albite twins only) indicated in one section $Ab_{65}An_{35}$ and in another $Ab_{74}An_{26}$. Quartz occurs in a few rounded or irregular single grains with partial crystal outlines and in many mosaics, some of which appear like shattered crystals and others like aggregates of rapidly formed grains. Many of the more distinct phenocrysts are somewhat corroded, especially on one side only, the other side retaining sharp boundaries. Bipyramidal inclusions of glass are present in some quartz crystals. Biotite forms a few irregular plates with resorption rims, but for the most part is completely resorbed and represented by linear groups of magnetite specks embedded in a finely granular colorless mineral, either unstriated feldspar or quartz, which could not be accurately determined. Some former grains not completely resorbed are now represented by chlorite. Magnetite and locally apatite and zircon occur as microphenocrysts among the still smaller anhedral grains of the groundmass. The magnetite forms some single crystals of square cross section but more commonly occurs in clusters or composite crystals. The groundmass is a minutely granular mosaic of quartz, alkalic feldspar, and plagioclase, specked with magnetite and containing scattered grains of chlorite or altered biotite. A few crystals of zircon are also present. The grains of feldspar are for the most part too small or too much altered to be distinguished, but where distinctions can be made the plagioclase tends to form hypautomorphic grains, whereas the quartz and alkalic feldspar grains are irregular.

Alteration products not already mentioned are tourmaline and pyrite. The tourmaline was found during the earlier survey in the east crosscut on the 350-foot level of the Swansea mine, now inaccessible.

According to the earlier report,[1]

> It is a megascopic constituent, small spots of the black mineral with its radiate structure and silky luster being scattered throughout the rock. In the thin section this quartz porphyry is characterized by an abundance of quartz phenocrysts, with irregular outlines due to magmatic resorption. The feldspars are badly altered, as is also the cryptocrystalline groundmass. The tourmaline occurs in aggregates of long acicular prisms, with the characteristic cross fractures. It is strongly pleochroic, the ordinary ray giving deep-blue and greenish-blue tints and the extraordinary varying from colorless to light brown. These radiate groups of tourmaline needles in part replace the feldspar and in part occur in the groundmass. In one instance an aggregate was noted abutting against the edge of a quartz phenocryst. This occurrence of tourmaline in a quartz porphyry has many points of resemblance to that described by Weed and Pirsson[2] from the Castle Mountain mining district, Mont. As remarked by these authors, this mineral is rarely found as a constituent of quartz porphyry, and the Castle Mountains and the Tintic Mountains are the only known American localities.

In some sections pyrite occurs in minute crystals and irregular grains in feldspar and quartz phenocrysts and in the groundmass. In others it is intimately associated with biotite and magnetite, suggesting a primary origin. It also fills minute fractures.

CHEMICAL COMPOSITION AND CLASSIFICATION.

Analysis 1 in the following table represents a light-gray microgranular porphyritic rock, containing phenocrysts of feldspar (somewhat altered) and quartz and small amounts of microscopic biotite, magnetite, apatite, and zircon, with secondary pyrite and chlorite.

This analysis is very close to the average of quartz porphyries (column 2) and nearer than that of the Packard rhyolite to the average of rhyolites. (See p. 49.) It also more closely resembles the great majority of analyses of Cordilleran rhyolites, quartz porphyries, and granites.[3] The differences between the Swansea and Packard rhyolites are only slight however and might easily be duplicated by analyses from different specimens of a single rock body. They may be accounted for by a slight increase of quartz and a corresponding decrease of feldspars in the Swansea rock. In

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 636.
[2] Weed, W. H., and Pirsson, L. V., Geology of the Castle Mountain mining district, Mont.: U. S. Geol. Survey Bull. 139, p. 99, 1896.
[3] See Washington, H. S., op. cit., pp. 165-217.

one thin section the plagioclase of the Swansea appears to be slightly more sodic than that of the Packard, but if the composition of the plagioclase is assumed to be $Ab_{74}An_{26}$, as determined for that section (which probably represents an outer zone), there is no excess of Na_2O over CaO to enter into the microperthite. If the composition determined for the other thin section examined ($Ab_{65}An_{35}$) is assumed, the composition and percentages of the modal feldspars will be plagioclase ($Ab_{65}An_{35}$) 30.17 per cent and alkalic feldspar ($Or_{84}Ab_{16}$) 30.85 per cent. These figures appear to be close to those indicated by the majority of thin sections, though in some the amount of albite in the alkalic feldspar seems higher.

Analyses of Swansea rhyolite and quartz porphyry.

	1		2
	Analysis.	Molecular ratio.	
SiO_2	71.56	1.193	72.36
Al_2O_3	14.27	.140	14.17
Fe_2O_3	[a] .89	.006	1.55
FeO	[a] Undet.	....	1.01
MgO	.42	.031	.32
CaO	1.18	.021	1.38
Na_2O	3.00	.048	2.85
K_2O	4.37	.047	4.56
H_2O-	.36	....	
H_2O+	.79	....	1.09
TiO_2	.38	.005	.33
ZrO_2	Undet.	....	....
CO_2	None.	....	....
P_2O_5	.13	.001	.09
MnO	Trace.	....	.09
BaO	.28	.002	....
SrO	Trace.	....	....
Li_2O	None.	....	....
Cr_2O_3	Trace.	....	....
V_2O_3	.01	.000	....
Cl	.06	.002	....
As	Trace.	....	....
FeS_2	2.29	.019	....
	99.99	....	100.00

[a] Total S is calculated as FeS_2; there is present, however, a trace of sulphide decomposable by acid. All Fe not as FeS_2 calculated as Fe_2O_3.

1. Swansea rhyolite, Swansea mine, Tintic mining district, Utah. H. N. Stokes, analyst. Tower, G. W., jr., and Smith, G. O., op. cit., p. 637.
2. Average of 50 analyses of quartz porphyry. R. A. Daly, compiler. Am. Acad. Arts and Sci. Proc., vol. 45, p. 219, 1910.

The ratio of plagioclase to alkalic feldspar in the Swansea rhyolite, as in the Packard rhyolite, may be regarded as a monzonitic character. The rock is practically identical in general composition with typical two-feldspar granites and is an interesting illustration of the point made by Watson[1] that most granites in the country are virtually quartz monzonites. The geologic relations of the Swansea rhyolite to monzonite are even closer than the similarity of chemical and mineral composition. According to the quantitative system the Swansea, like the Packard rhyolite, is classified as toscanose (I.4.2.3).

RHYOLITE DIKES.

The rhyolite dikes, which are best seen in the lower workings of the Opex mine, closely resemble the Swansea rhyolite megascopically, though their microscopic features are not quite the same. The rock is dark greenish gray, dense and porphyritic. Quartz and feldspar are its only recognizable original minerals, and it is highly impregnated with fine pyrite crystals. It is for the most part much decomposed, probably from the effects of partial oxidation of the pyrite, and caves in soon after it is exposed in the workings. Only one thin section, that of a specimen from a chilled contact, was studied. The microscopic appearance of the rock is more like that of andesitic or monzonitic than of rhyolitic rock, owing to the prominence of narrow plagioclase laths in the groundmass. The plagioclase is too much obscured by alteration to sericite and calcite to be accurately determined. Only one very doubtful crystal of alkalic feldspar was noted. Quartz forms here and there a bipyramidal crystal with groundmass inclusions but occurs mostly in small aggregates and in poorly defined single granules which are virtually a part of the groundmass. The black silicates are all destroyed, but biotite is suggested by the outlines of several thin, lath-shaped areas, and augite by the outline of certain calcite-chlorite aggregates like those which replace augite in the monzonite and latites of the district. Magnetite and apatite occur in typical forms. The groundmass is very finely and incompletely crystalline. It appears to consist mostly of plagioclase, with considerable quartz and some alkalic feldspar in interstitial anhedrons.

[1] Watson, T. L., Intermediate (quartz monzonitic) character of the central and southern Appalachian granites, with a comparative study of the granites of New England and the western United States: Virginia Univ. Philos. Soc. Bull., Sci. ser., vol. 1, No. 1, pp. 1-40, 1910.

The observed mineral composition, which closely resembles that of the rhyolitic phase of the monzonite around the large quartz inclusion (p. 68), is intermediate between that of the Swansea rhyolite and that of the monzonite, the absence of conspicuous alkalic feldspar and the presence of possible augite suggesting the monzonite, and the phenocrysts of quartz pointing toward the rhyolite. The variation from the rhyolite, however, may be more textural than chemical, for this marginal phase of the rock may have been chilled before crystallization of the alkalic feldspar, which in the local rocks follows that of the plagioclase, had proceeded far enough to produce conspicuous phenocrysts.

RHYOLITE OF TINTIC MOUNTAIN.

The rhyolite on the west slope of Tintic Mountain was not visited during the recent survey, but as it is distinct in appearance from the others, the following description is given. It should lie, according to the earlier map, within the lower part of the latite-andesite series, though the possibility of postvolcanic faulting throws some doubt on its exact position. It is of very light gray color where fresh and of dense porphyritic texture. The only visible mineral is sanidine in colorless lath-shaped crystals showing distinct Carlsbad twinning. The rock in thin section is porphyritic with a trachytic groundmass. The phenocrysts are plagioclase, sanidine, and biotite. None of quartz were noted. In one thin section rectangular crystals of plagioclase as much as 3 millimeters long outnumber those of sanidine; in another section the reverse is true. The plagioclase is faintly zoned, is twinned according to both Carlsbad and albite laws, and has the extinction angles of calcic oligoclase or sodic andesine. The sanidine crystals are all Carlsbad twins in parallel alignment and with curved ends resembling the prow of a boat. They have a rough parting parallel to 100. One sanidine crystal inclosed a small crystal of plagioclase of greater refractive index, which accords with the extinction angles found. Both feldspars are free from conspicuous weathering. Biotite, which is scarce, forms crystals 1 millimeter or less in diameter with light-yellow to deep reddish-brown pleochroism. It is partly weathered to limonite. The groundmass is made up of feldspar laths, a few of which have albite twinning and all of which have approximately parallel extinction. They probably comprise both oligoclase and sanidine but are too minute to permit exact distinctions.

Partial analysis and norm of rhyolite on west slope of Tintic Mountains.

Analysis.		Partial norm.	
SiO_2	70.30	Quartz	21.36
MgO	None.	Orthoclase	34.47
CaO	1.00	Albite	35.63
Na_2O	4.18	Anorthite	5.00
K_2O	5.83		96.46
	81.31		

Although the absence of quartz even in thin section suggests the name trachyte, the high percentage of silica in the analysis and that of quartz in the norm show that the rock should be classified with the rhyolites. The free silica evidently forms minute interstitial films, too small to be detected, among the feldspars of the groundmass. The ratio of albite to anorthite in the norm is greater than that indicated by the optical properties of the plagioclase and implies that a considerable proportion of the albite is present in the sanidine, and also that the plagioclase in the groundmass is more sodic than the phenocrysts. The sodic character of the alkalic feldspars is a feature common to the Packard and Swansea rhyolites. The total lack of magnesia does not fully accord with the results of optical study, but the biotite is so scarce and thinly scattered that the small chips used for analysis may not have contained any.

This rock, as compared to the earlier rhyolite, is more distinctly crystallized and very free from silicification and hydration. The two rocks therefore can not be correlated on microscopic evidence, but the probable position of the rhyolite west of Tintic Mountain, within the lower part of the great latite-andesite series, may not be far from that of the earlier rhyolite. The rhyolite of Tintic Mountain differs physically from the Packard and Swansea rhyolites in the absence of quartz phenocrysts and in the trachytic character of the groundmass. In percentage of silica, however, it lies between the two. It is a little higher in the alkalies and lower in lime and magnesia.

POSTRHYOLITE IGNEOUS ROCKS.

GENERAL RELATIONS.

Igneous rocks erupted later than the rhyolites just described include a great series of effusive latites and possibly andesites, only a small part of which were examined during the recent survey, intrusive bodies of monzonite porphyry and monzonite, and small intrusive sheets of basalt. (See Pl. I.) These, so far as possible, are described in the order of geologic sequence, which has been definitely determined only at the few places cited in the following table. The proofs or indications of the sequence at these places are given in the descriptions of the different rocks.

Sequence of postrhyolite igneous rocks in Tintic district.

Volcano Ridge and Sunrise Peak.	Vicinity of Sunbeam mine.	East of Northern Spy shaft.	South of Laguna station.
Monzonite porphyry dikes. Monzonite porphyry and associated latites. Augite latite.	Monzonite. Monzonite or latite (?) porphyry.	{Coarser biotite-augite latite. {Finer augite-biotite latite.	Hornblende-biotite-augite latite.
Tuff and agglomerate with rhyolite fragments.	Tuff.	Interbedded tuffs and latites.	Tuff and agglomerate.
Rhyolite (mostly inclusions).		Rhyolite.	Rhyolite.

LATITE TUFFS AND AGGLOMERATES.

VOLCANO RIDGE.

The lowest member of the series, wherever the sequence can be definitely determined, is latite agglomerate and tuff. It is best exposed around Volcano Ridge, over 2 miles southwest of Diamond, where it forms a very thick series of beds, dipping concentrically away from the nose of the ridge, which was evidently a center of eruption. The present writer has studied it only along the southeast base of Sunrise Peak and the crest of Volcano Ridge, and his observations confirm Smith's description in the earlier report,[1] which is as follows:

The western half of Volcano Ridge is seen to be the remnant of a deeply eroded volcanic zone. Erosion has so well exposed the different parts of the old volcano that the character of the eruption and the sequence of its products can be quite definitely determined.

The volcanic center is indicated in two ways. The thick beds of fine and coarse greenish tuffs have dips of 10° to 20°. These pyroclastics have sheets of andesite interbedded with them, and their strikes express roughly a semicircular arrangement. The area covered by this series of tuffs is something over 2 square miles and clearly represents a section of a volcanic cone. The point indicated as the center from which these fragmental deposits dip is approximately the nose of this ridge, and examination of this locality furnished the second piece of evidence as to the position of the volcanic vent.

The western end of Volcano Ridge has an elevation of over 7,000 feet, and thence the descent is sharp to Tintic Valley. At this point the bedded tuffs give place to a rock which is strikingly agglomeratic. On the knob just east of the end of the ridge limestone blocks of cobblestone size are abundant in the coarse tuffaceous material. As the nose of the ridge is reached blocks of quartzite become more abundant than those of limestone. Several masses of white vitreous quartzite occur, standing 20 to 30 feet above the dark-green and gray volcanic material. These blocks are plainly embedded in the latter material, as the softer material has been eroded away in several cases so that the lower surface of the quartzite block is exposed. * * * Rhyolitic material is also found on the slopes at this locality and is extremely fragmental in character. The agglomerate here in its coarsest phase contains fragments of rhyolite, andesite, quartzite, limestone, and shale, while the finer portions are seen under the microscope to contain mineral fragments as well as particles of glass, the latter exhibiting somewhat of an ash structure.

With this agglomerate are associated irregular sheets and dikes of andesite, the whole presenting rather confused relations [though many of the dikes have roughly radial positions as shown in Plate I]. This intimate mixture of lava and pyroclastic material is such as might be expected at or near a volcanic vent. Dikes of andesite porphyry are also prominent on the slopes of Volcano Ridge.

On the extreme end of Volcano Ridge, not far above the valley level, there occurs a mass of quartzite several hundred feet in diameter. This and a much larger area of quartzite somewhat over a mile distant to the southeast doubtless represents uncovered portions of the underlying quartzite which was engulfed in the flows of lava and deposits of volcanic ejectamenta. The presence of three kinds of sedimentary rock in the agglomerate shows that the point of eruption was close to the contact of the Robinson [Tintic] quartzite [which was mapped to include the overlying shale or slate] and the Eureka [Teutonic] limestone. [A small uncovered limestone area near the eastern end of Volcano Ridge confirms this conclusion.]

[1] Tower, G. W., jr., and Smith, G. O., op. cit., pp. 653-654. "Andesite" in the earlier report was intended to include the latites as well as any true andesites in the district.

It is probable that the Volcano Ridge vent was but one of several eruptive centers, as extremely coarse breccias occur in the volcanic series of Long Ridge, about 9 miles to the southeast. On Volcano Ridge, however, the relations are best exposed, and this volcanic center is more fully described since it is believed to be typical of the earlier eruptions of [the postrhyolite] andesite in the Tintic Mountains.

The inclusions of rhyolite prove that the andesitic agglomerate and tuff are later than the rhyolite in this vicinity, but those of andesite show that the agglomerate and tuff do not represent the very earliest andesitic eruptions. That they are older than any of the adjacent volcanic rocks is proved by their eastward dip beneath the flows and by the clearly intrusive contact of the monzonite porphyry to the north.

The small area of coarse and fine grained to slaty tuff northeast of Sunrise Peak is clearly a northward continuation of the Volcano Ridge series, cut off from it by the later intrusive Sunrise Peak mass and uncovered by the erosion of overlying flows. It dips gently northeastward and its contacts are for the most part well exposed as far north as Diamond. Thence northward it dips beneath the surface, but its exact boundaries are concealed by talus and alluvium.

The character and extent of the material at Horseshoe Hill, west-southwest of Diamond, is greatly obscured by profound alteration and disintegration. Hardly anything but bleached débris can be found, some clearly of tuff and some quite undeterminable. Thin sections prove its similarity in texture and composition to the finer tuff of Volcano Ridge.

Another small body of tuff, only doubtfully correlated with the tuffs of Volcano Ridge, is found on the low spur south of the Sunbeam mine. Here, too, the lithologic character and structure of the material are greatly obscured by profound alteration and disintegration. Undoubted tuff can be recognized at a few points from the Triumph shaft southward, but absolutely no structure can be determined. In fact, alteration has so thoroughly bleached both the tuff and the adjacent monzonite porphyry that only the most generalized boundary can be drawn between them. The fact that the tuff is inclosed or possibly overlain by monzonitic porphyry, together with its composition as shown by the microscope, affords the basis for its correlation. So far as general appearance and location go, it might be considered a thoroughly altered mass of the rhyolitic tuff, which evidently extended farther south of Sioux Pass than its present outcrop, but in the absence of any closely associated earlier rhyolite or Packard rhyolite, all evidence to prove such a correlation is lacking.

LAGUNA.

Another distinct series of latite or andesite agglomerate and tuff is exposed in the gorge of Pinyon Creek at Laguna station, near the northern boundary of the Tintic quadrangle. It lies directly upon the obsidian at the top of the Packard rhyolite and beneath one or more flows of latite or andesite. It has been traced southeastward over 2 miles but is concealed through much of this distance by talus. It may extend much farther south than the map indicates but was not noted during the short time devoted to the reconnaissance east and south of Goshen Slope. Its texture is very uneven. It includes some distinct beds of very fine, soft sandy tuff, almost free from angular pebbles, but in most exposures large cobbles of obsidian are embedded without definite arrangement in the finest matrix. The textural character suggests correlation with the volcanic series of Long Ridge mentioned in Smith's statement and further emphasizes his opinion that andesitic tuffs must have been erupted from more volcanic centers than the one at Volcano Ridge. The table on page 54 shows that the Laguna tuff, like that of Volcano Ridge, lies at the base of the latite-andesite series, but study of the map (Pl. I) will show that the two bodies of tuff can not be products of the same eruption. Such a correlation would also have to account for the fact that the tuff at Laguna, far removed from the center of eruption, is much coarser than most of the material close to the center itself.

Other beds of tuff, noted during the earlier survey but not visited by the writer, occur northeast of Diamond Divide, north and west of Tintic Mountain, in Big Dog Canyon, and on Long Ridge.

LITHOLOGY.

The megascopic character of the latite tuffs has been described in the preceding paragraphs. In thin section the inclosed rock fragments include latite or andesite, quartzite, limestone, and a little glassy lava; the mineral

fragments are plagioclase, augite, hypersthene, biotite, magnetite, quartz, and alteration minerals, including chiefly chlorite, epidote, sericite, calcite, quartz, and chalcedony or opal. Plagioclase is the most abundant mineral and includes some grains of so acidic a composition that they may well be fragments of phenocrysts from the older rhyolite. The primary quartz is probably derived from the older rhyolite and is in some sections, together with angular areas of secondary quartz, sufficiently abundant to give the appearance of rhyolitic tuff. Certain thin sections from Volcano Ridge, Crystal Canyon, and Horseshoe Hill present this appearance, but in the altered tuff south of the Sunbeam mine the little quartz present is evidently all secondary, and in this respect the material differs from the rhyolitic tuff farther north.

AUGITE LATITE OF VOLCANO RIDGE.

DISTRIBUTION.

Directly overlying the tuffs of Volcano Ridge is a flow of augite latite, about 300 feet thick, dipping gently southeast. Its effusive character is marked by an upper vesicular or amygdaloidal phase seen in the saddle north of Buckhorn Mountain. Two sections across it were made, one just southeast of Sunrise Peak and one along Volcano Ridge, and in neither was any evidence found to prove the presence of more than one flow of rock of this type. It has not been followed south of Volcano Ridge. Toward the north it thins somewhat and is cut off and covered by the mass on Sunrise Peak. It has not been found north of Sunrise Peak in its expected position above the tuff in Crystal Canyon. Eastward-dipping sills of rock of the same type in the tuff of Volcano Ridge, together with the evidence above mentioned, suggest that the augite latite was erupted from the Volcano Ridge vent and flowed southeastward but did not extend northward beyond the position of Sunrise Peak.

LITHOLOGY.

The rock is dark greenish gray, dense, and finely porphyritic, containing lath-shaped phenocrysts of plagioclase and of shiny black augite that range from mere specks up to crystals 3 millimeters long but average less than 2 millimeters. The two minerals are about equally abundant, though the plagioclase may slightly predominate.

In thin section the plagioclase phenocrysts have extinction angles indicating a composition near $Ab_{30}An_{70}$. They are as a whole unaltered, but a very few crystals are slightly impregnated with small granules of epidote and chlorite and minute needles resembling uralite. The augite phenocrysts have a pale-green to yellow pleochroism. The larger crystals are partly and some of the smaller ones completely altered to the same secondary minerals that were noted in the feldspar. Apatite and magnetite are conspicuous under a high power, forming microphenocrysts of typical shapes. The groundmass appears to consist of a glassy base crowded with minute laths of plagioclase and with the alteration products of augite granules, which tend to produce a more or less distinct ophitic texture.

A partial chemical analysis and the corresponding partial norm are given below.

Partial analyses and norm of augite latite.

Analyses.			Norm.	
	1	2		
SiO_2	53.75	57.65	Excess silica	1.56
MgO	3.30	3.22	Orthoclase	24.46
CaO	5.95	[a] 5.74	Albite	27.47
Na_2O	3.18	3.59	Anorthite	29.47
K_2O	4.13	4.39	Magnesium metasilicate	10.82
	70.31	74.59		93.78

[a] Includes 0.16 per cent BaO and 0.07 per cent SrO.

1. Augite latite of Volcano Ridge. George Steiger, analyst.
2. Average latite. Daly, R. A., Average chemical compositions of igneous rock types: Am. Acad. Arts and Sci. Proc., vol. 45, p. 221, 1910.

The amount of potash, corresponding to 24.46 per cent of orthoclase, is especially noteworthy, as no orthoclase or biotite was detected in thin section, and therefore they must be present in the glassy groundmass. This feature is sufficient to classify the rock as a latite, as is also the close similarity between analyses 1 and 2 in the above table. The ratio of albite to anorthite in the norm does not correspond closely to the ratio indicated by the optical characters of the plagioclase phenocrysts, and the discrepancy is even more obvious if it is realized that a considerable part of the normative anorthite belongs to augite. This is explained by the probability

that the plagioclase laths in the groundmass are more sodic than the phenocrysts and that a considerable part of the soda may, like all the potash, be represented by the glassy part of the groundmass. The pleochroism of the augite, furthermore, suggests that it may contain a small amount of the aegirite (soda-iron pyroxene) molecule. The small excess of silica in the norm is doubtless no more than enough to enter with iron into the augite. It is improbable that there is any free silica, equivalent to quartz, in the glassy groundmass, and in this respect the augite latite differs from the principal intrusive bodies of monzonite and monzonite porphyry.

The amygdaloidal variety at the top of the flow is more greenish in color and contains elongate amygdules filled with calcite, more or less chlorite (pennine), and opaline silica. Where conspicuously weathered it is bleached to a gray and the amygdules are completely leached out save for a little residue of yellow earthy limonite. In thin section the augite is nearly all replaced by aggregates of calcite and chlorite (delessite?), and the plagioclase has altered to calcite and sericite with a little chlorite and chalcedonic or opaline silica. The texture of the groundmass is still distinct.

OTHER OCCURRENCES OF AUGITE LATITE OR ANDESITE.

Thin sections of specimens of augite andesite (or latite) collected during the earlier survey were also studied. At two localities, west of Tintic Mountain and north of Diamond Divide, the microscopic features of the rock, including the composition of the plagioclase (near $Ab_{30}An_{70}$) are quite like those of the augite latite of Volcano Ridge. The rock west of Tintic Mountain, according to the topographic map, may well be the southward continuation of the same flow, but such a correlation of the rock north of Diamond Divide would probably necessitate the presence of a fault with upthrow on the east. Similar rock occurs west of Slate Jack Canyon and east of Long Ridge.

MONZONITE PORPHYRY AND RELATED LATITE FLOWS.

DISTRIBUTION AND STRUCTURAL RELATIONS.

Sunrise Peak, south of Diamond, is composed entirely of a uniform mass of dark-gray to greenish-gray porphyry, having the chemical composition of monzonite but ranging in texture from monzonite to latite. It is geologically one of the most significant rock masses in the quadrangle, for it shows the connection of flows with a second volcanic neck. The contacts around Sunrise Peak, where well exposed, are clearly intrusive. This relation is best shown in the canyons along the southeast and northeast bases of the peak, where vertical dikes of the Sunrise Peak rock project into the beds of tuff erupted from the first vent. As the tuff bounds Sunrise Peak on three sides (see Pl. I) the whole peak must be considered an intrusive mass. Many of the dikes on the nose of Volcano Ridge are similar in megascopic appearance and composition to the rock of Sunrise Peak and may be in part a product of the same eruption.

The connection between the Sunrise Peak mass and undoubted surface flows is perfectly exposed along the east half of the peak. On the southeast side the contacts with tuff and above this with the fine augite andesite are clearly marked, but above the andesite the Sunrise Peak rock continues across the saddle and forms the neighboring summits to the east. As the distance increases flow structure and brecciation typical of effusive lavas may be noticed, but any changes in structure and texture are so gradual that texture alone can not serve to indicate the intrusive or effusive nature of the rock. In fact, it is impossible to distinguish between hand specimens taken from the summit of Sunrise Peak and from the peaks and ridges immediately to the east or northeast, including the ridge northeast of Diamond. (See Pl. I.)

How many flows were erupted from the Sunrise Peak vent is not known. So far as is shown by any positive evidence in the disintegrated outcrops directly east of Sunrise Peak, there may be but one enormous flow; but on Buckhorn Mountain, a mile farther south, there appear to be at least two, and detailed work may disclose several.

In Crystal Canyon, on the northeast side of Sunrise Peak, the tuff is clearly shown to be cut on its west side by the intrusive rock and to be overlain on its east side by rock of the same type in nearly horizontal position. Just east of Diamond one of the dikes can be followed across the canyon and up the slope through the tuff to a point where it connects with the overlying rock.

North of Diamond, where the tuff pitches below the surface, no boundary can be drawn between the intrusive and the effusive rock. The ridge to the northeast must consist of effusive rock, but the rocks in the area north of Diamond Gulch, including Treasure Hill, and in the area north of Ruby Hollow as far as the vicinity of Sioux Pass, are of doubtful character. The rocks in and around the areas of poorly exposed tuff north and south of Ruby Hollow are so thoroughly bleached and disintegrated that the character of their contacts with the monzonite porphyry could not be determined. It is therefore not known whether the rock of Treasure Hill is a northward extension of the Sunrise Peak intrusion and cuts up through the tuff or is a westward continuation of the ridge northeast of Diamond and overlies the tuff.

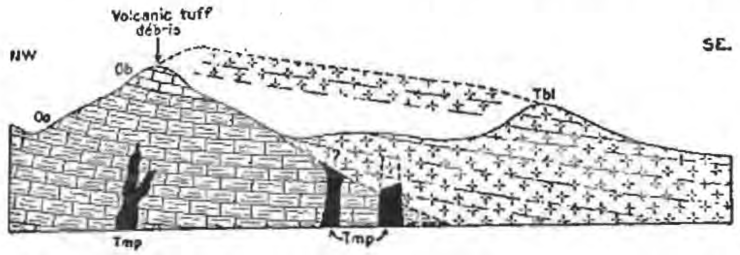


FIGURE 6.—Double section along lines trending S. 55° E., showing relation of porphyry to limestone south of Sioux Pass. Oo, Opohonga limestone; Ob, Bluebell dolomite; Tbl, biotite latite; Tmp, monzonite porphyry.

North of Ruby Hollow the texture of the highly disintegrated porphyry shows nothing strongly indicative of effusive character, but the position of the rock, east of the tuff, is suggestive of it, as is the nature of the limestone and porphyry contact from the Dragon iron mine northward to Sioux Pass. (See figs. 6 and 7.) The workings of the Dragon mine (figs. 8 and 9) have proved that the limestone surface slopes steeply southward beneath the porphyry, and the intrusive contacts exposed on 800 and 1,000 foot levels are those of the monzonite of the Silver City stock, not the porphyry under discussion. On the surface the boundary of the porphyry, marked by disintegrated and thoroughly altered material, extends obliquely up the slope to Sioux Pass, where it becomes confused with bleached rhyolitic material of spherulitic and tuffaceous texture. At no place is the contact well enough exposed to give definite evidence, but from the facts that the limestone surface appears to slope beneath the porphyry and that there is no change in the texture of the porphyry, whether close to or remote from the contact, the interpretation of the porphyry as an effusive seems plausible. A more convincing argument is furnished by the quite different character of the monzonite contact of the Silver City stock, where rock of granular texture extends within a very few feet of the surface, even in the small area just north of Sioux Pass. Moreover, the monzonite contacts, where not vertical, slope beneath the limestone, or in a direction just opposite to that of the monzonite (or latite) porphyry. (See figs. 8 and 9.)

The highly metamorphosed character of the limestone along the contact around the Dragon iron mine may suggest that the porphyry at this place is intrusive; but whereas contact metamorphism is conspicuous in the canyon bottom, it is absent along the contact at the top of the ridge just north of the Governor shaft, although the limestones here must have formed the footwall of the contact. The same limestones have undergone metamorphism to the northeast and west, near contacts with the undoubted monzonite, which is believed to be a later intrusion, and it is quite possible, for the

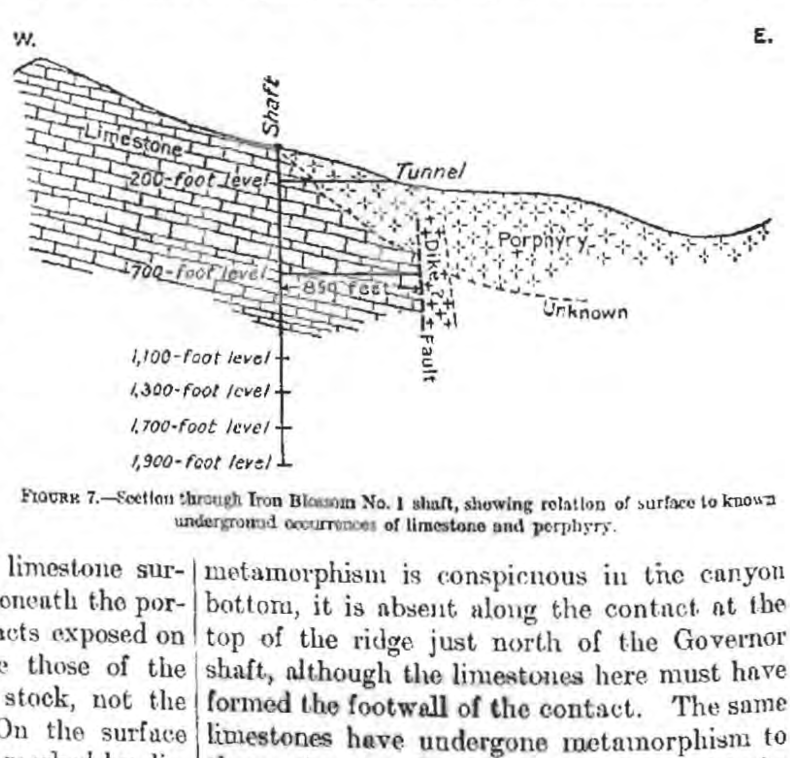


FIGURE 7.—Section through Iron Blossom No. 1 shaft, showing relation of surface to known underground occurrences of limestone and porphyry.

following reasons, that all the contact metamorphism may be attributed to this rock. The distribution of contact metamorphism shows a direct relation to the positions of the main monzonite body east of Diamond Pass and the small stock east of the Carisa mine, strongly suggesting that the two are connected at no very great depth. The eastward bulge of the granular monzonite at the Martha Washington shaft, the presence of intrusive monzonite on the 800 and 1,000 foot levels of the Dragon iron mine south of the shaft and in the lower part of the drill hole east of the Brooklyn shaft (fig. 8), the exposure of a granular monzonite dike in probable effusive porphyry along the railroad 4,500 feet farther northeast, and the presence of dikes in the Iron Blossom No. 1 workings, point to a parallel northeastward extension of the monzonite which may have produced the metamorphism in and around the Dragon iron mine. It also seems more reasonable to regard the metamorphism as due to an underlying extension of the granular monzonite than to the quickly chilled monzonite porphyry of the Sunrise Peak eruption.

The above outlined evidence, though not entirely convincing, favors the interpretation of the porphyry north of Ruby Hollow and west of Ruby Canyon as effusive. On the east side of Ruby Canyon, along the southward-sloping spur, the rock, which is mostly bleached, is of the same character as that on the west side, but at the north end of the spur and from that point along the east-west ridge the effusive character is clear beyond possible doubt. The exposures here have distinct taxitic and rather well-defined fluidal structure, and porphyritic rock alternates with obscure masses of tuff. Along the eastern half of the ridge distinct beds of coarsely and finely porphyritic texture were recognized, the coarse overlying the fine. The same relation between coarsely and finely porphyritic beds exists 2 miles farther east, beyond the small patch of Packard rhyolite, and adds somewhat to the evidence indicating the direction of faulting shown on the map (Pl. I).

No further attempt was made in the time available to study the extent of the effusive rocks connected with the Sunrise Peak eruption, or to distinguish different flows. On the

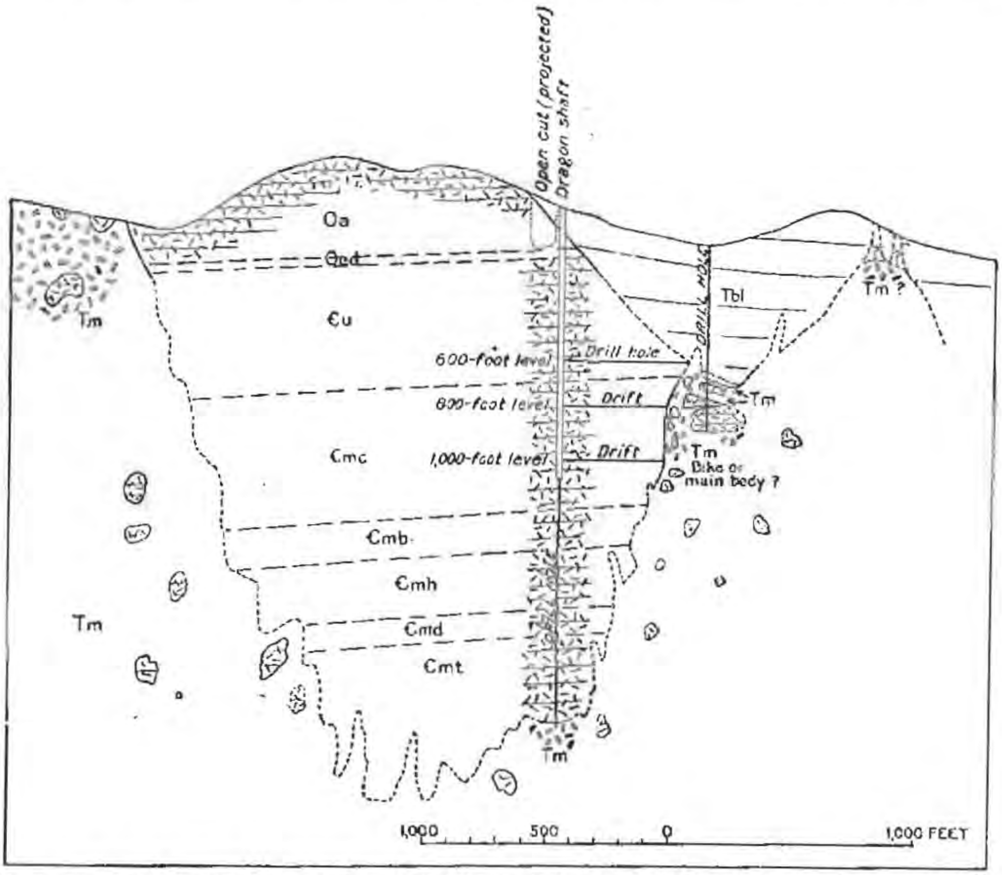


FIGURE 8.—Section through Dragon shaft and drill hole east-southeast of Brooklyn shaft (along line D–D, Pl. IV), showing underground extent of limestone and porphyry. For explanation of symbols see Plate IV.

map the area actually studied is shown and the portion known to be occupied by intrusive rock is distinguished from that in which the rock is of uncertain or probable effusive character. The remaining and by far the larger part of the latite-andesite area is indicated without subdivision, but it is said in the earlier report[1] that the mica andesites (that is, the rocks of the Sunrise Peak type) are confined in general to the eastern slope of the central portion of the range.

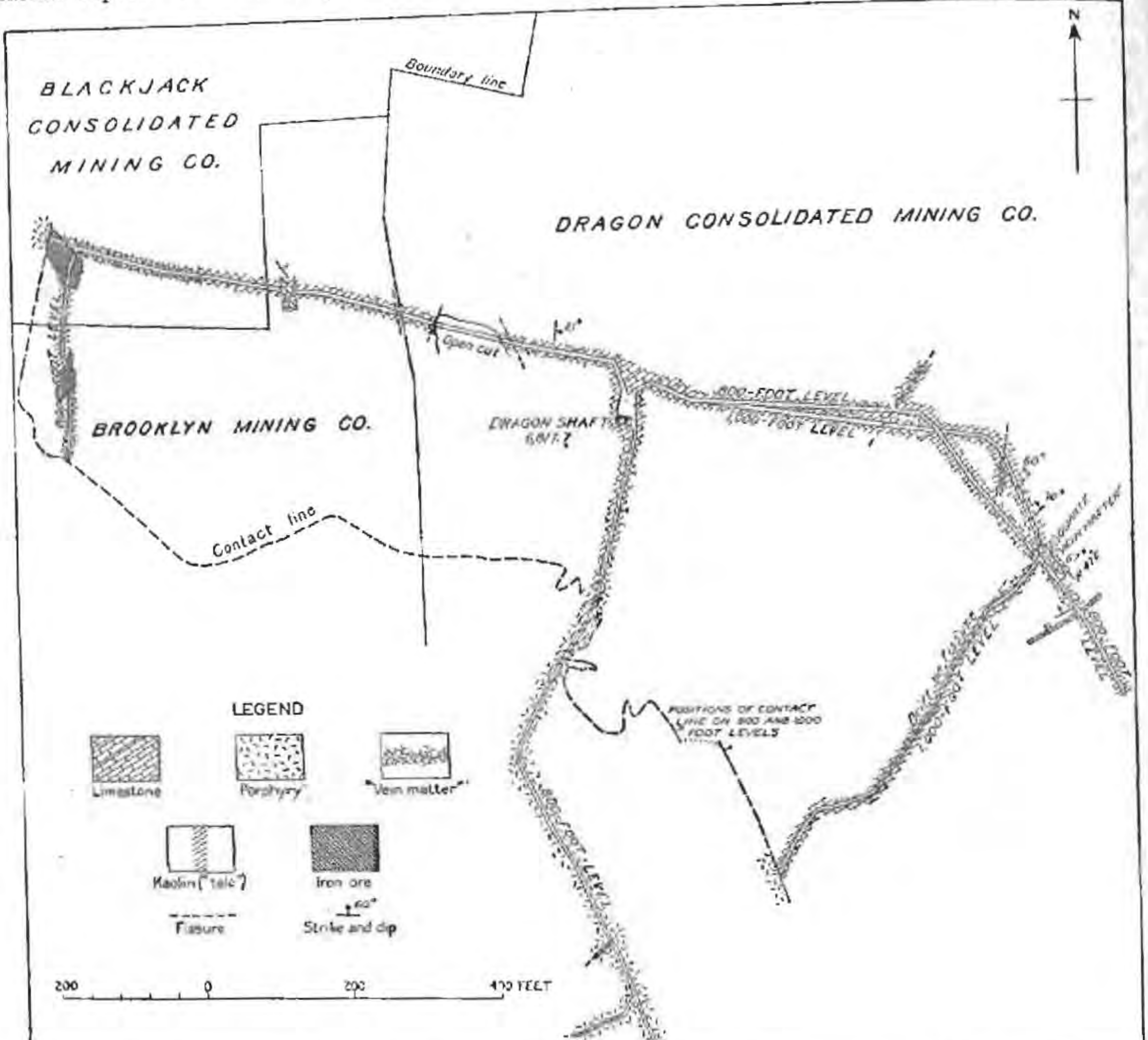


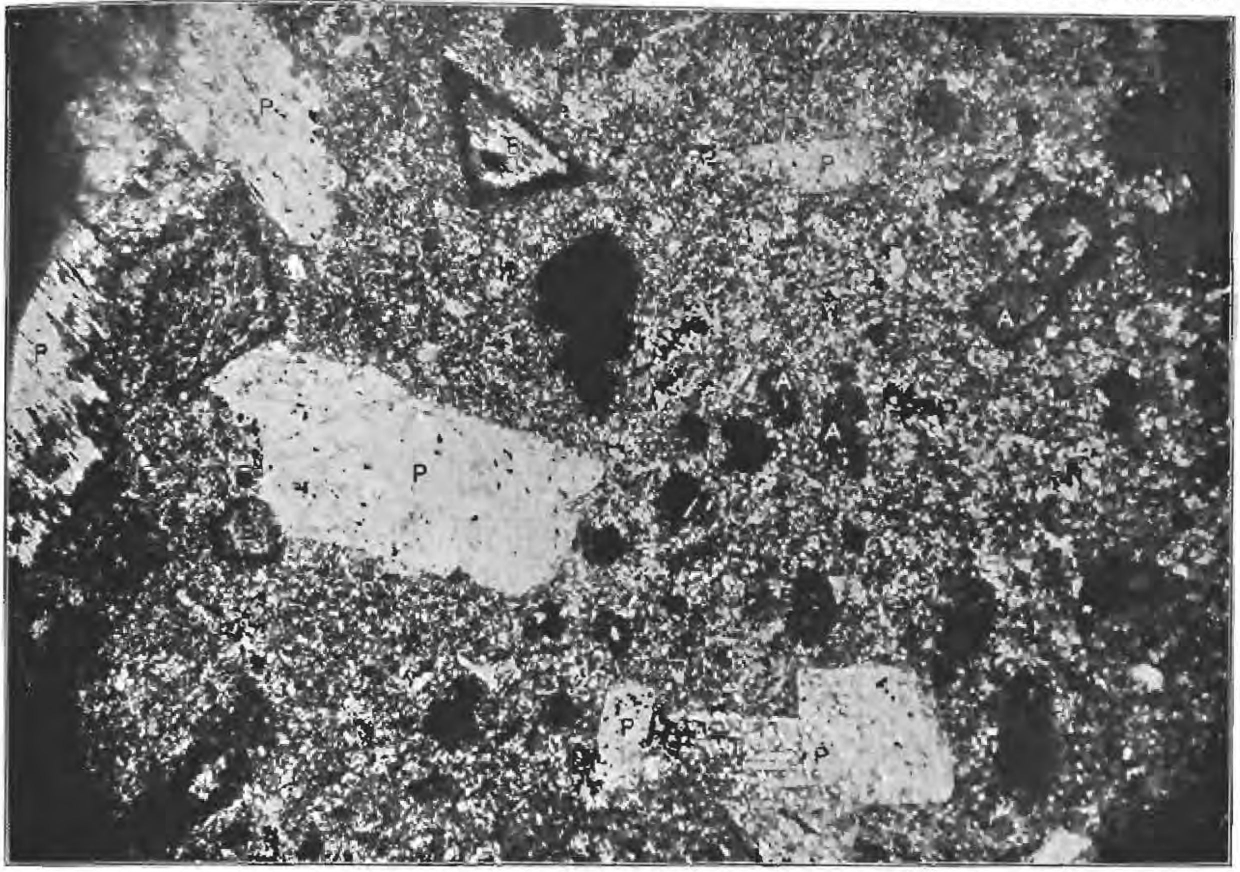
FIGURE 9.—Plan showing monzonite contacts on 800 and 1,000 foot levels of Dragon mine.

LITHOLOGY.

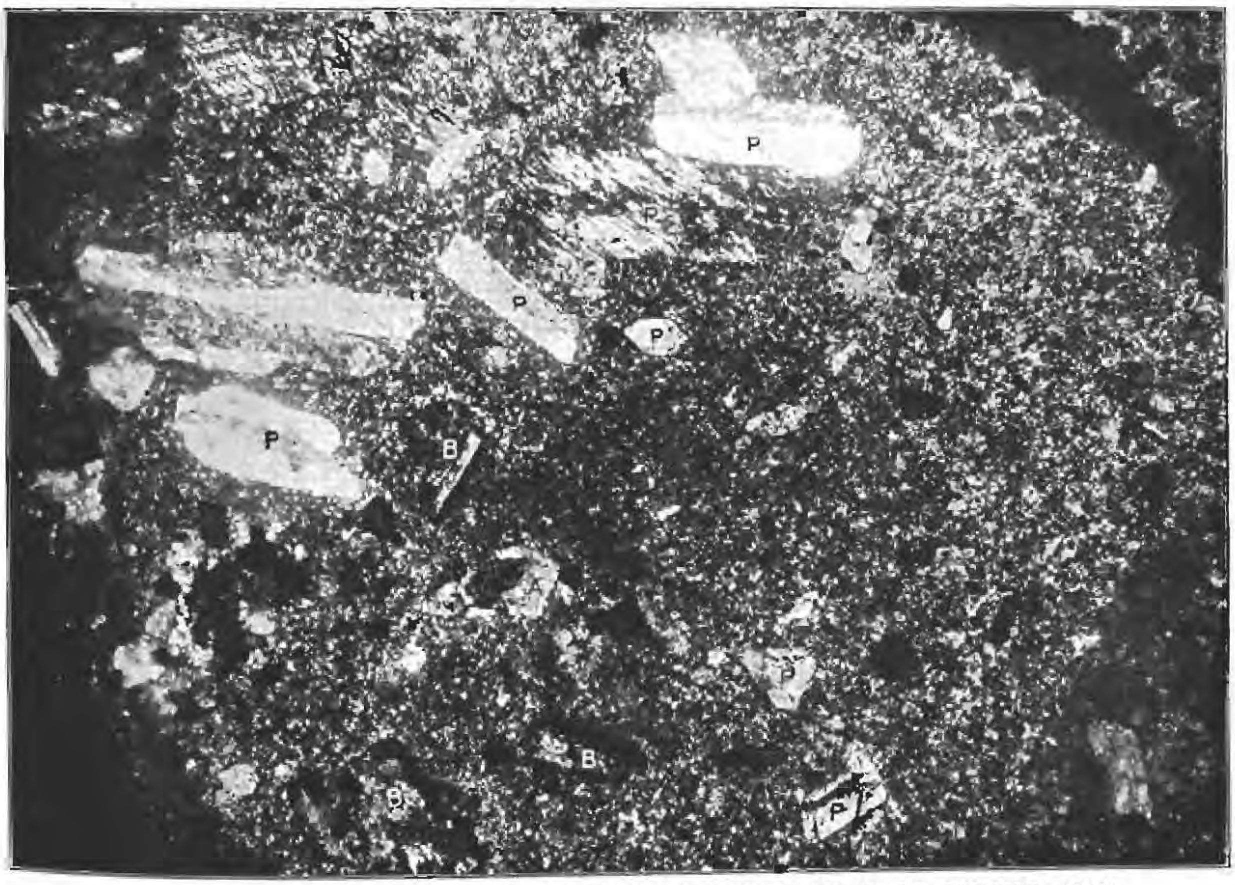
The rock at Sunrise Peak is dark gray to greenish or brownish gray where reasonably fresh, but with increased weathering becomes bleached to chalky white more or less blotched with yellowish limonite stains. Its texture is dense and porphyritic, phenocrysts constituting about 30 per cent of the rock. The megascopic phenocrysts are plagioclase, biotite, and in some places augite. The plagioclase forms single and composite lath-shaped crystals, averaging 3 millimeters in length, with both Carlsbad and albite twinning. The biotite forms conspicuous 6-sided crystals from 1 to 3 millimeters in diameter. Its color varies from shiny black where fresh to greenish and brown where altered or nearly white where leaching has been extreme. Augite forms minute irregular pitchy black grains. Its former presence in weathered specimens is marked by small pale rusty spots.

In thin section the rock of Sunrise Peak is seen to range from quartz monzonite porphyry

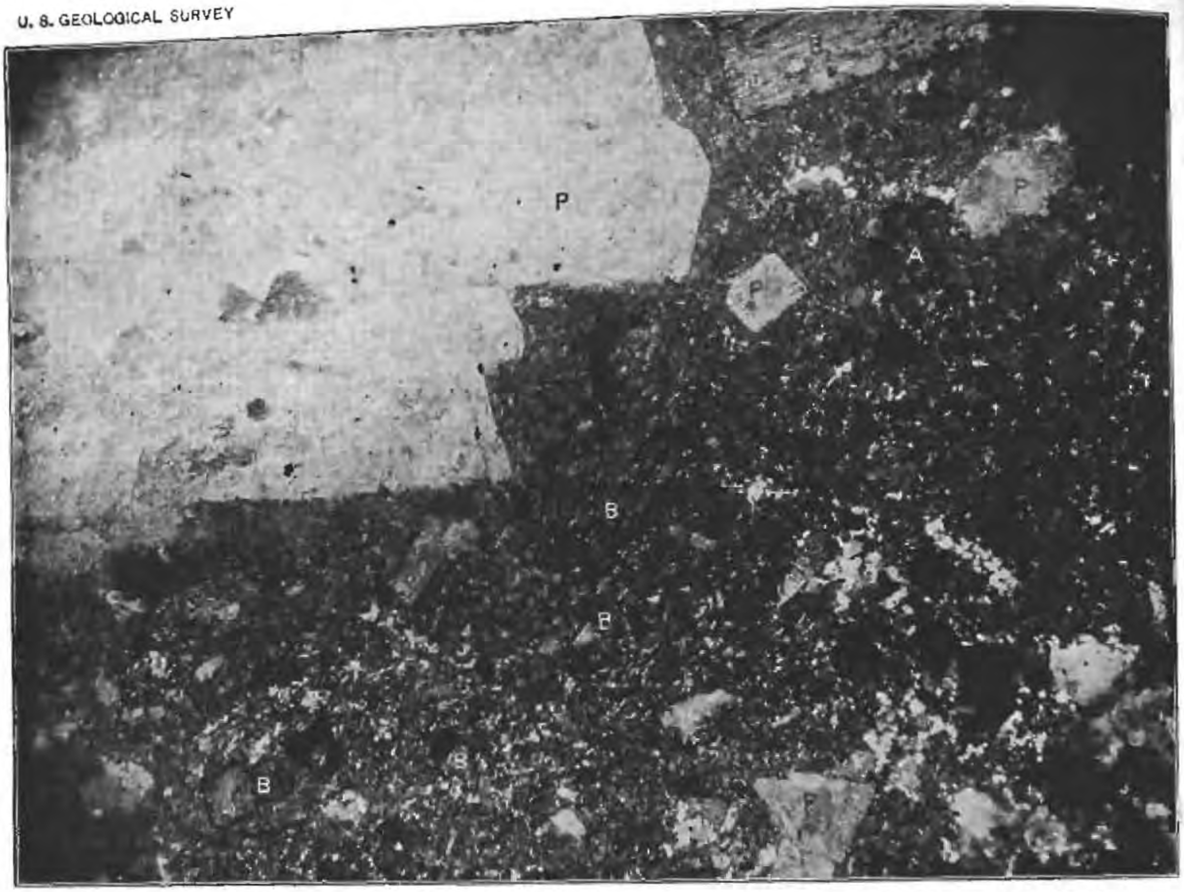
[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 639.



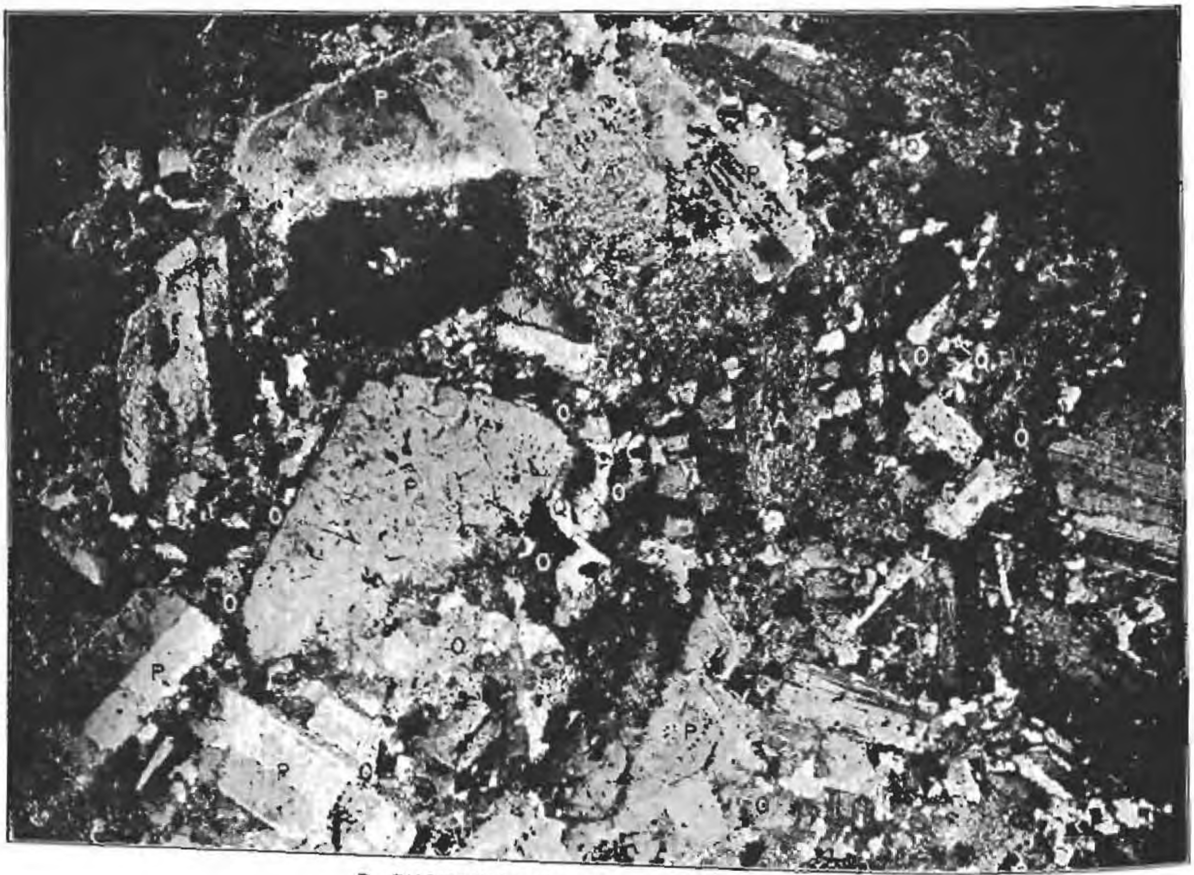
A. PHOTOMICROGRAPH OF MONZONITE PORPHYRY FROM WEST SLOPE OF SUNRISE PEAK.
P, Plagioclase; B, biotite; A, augite. Magnified 40 diameters.



B. PHOTOMICROGRAPH OF LATITE PORPHYRY FROM SUMMIT OF SUNRISE PEAK.
P, Plagioclase; B, biotite; A, augite. Magnified 40 diameters.



A. PHOTOMICROGRAPH OF LATITE PORPHYRY FROM RIDGE EAST OF TREASURE HILL.
P, Plagioclase; B, biotite; A, augite. Magnified 40 diameters.



B. PHOTOMICROGRAPH OF MONZONITE.
P, Plagioclase; O, orthoclase; Q, quartz; A, augite. Magnified 24 diameters.

to latite porphyry. The plagioclase is too much altered and too poorly oriented to be accurately determined, but in most sections its extinction angles indicate a composition near $Ab_{50}An_{50}$. The usual alteration products, sericite, epidote, and calcite, are present, and in some sections chlorite (pennine) also, which replaces certain zones of the plagioclase. The biotite is very conspicuous and where unaltered is quite typical. Most of its crystals are in greater part or wholly altered to chlorite (pennine) accompanied by more or less epidote and in a few sections by calcite. The augite occurs mostly in poorly shaped prisms and irregular grains, 1 millimeter or less in major diameter, and most of it is virtually a constituent of the groundmass. Many of the larger grains are simply twinned and show a distiuct pale-green to yellowish-white pleochroism. It is more or less altered to chlorite (pennine or locally delessite ?), epidote, and calcite. Magnetite and apatite form typical microphenocrysts, and in one section several small titanite crystals were noted, one of them inclosed in biotite.

The groundmass varies in texture. In some sections—for instance, from the lower west slope of Sunrise Peak and from one of the dikes extending into the tuff—it is microgranular and shows the composition of a quartz monzonite, containing short, distinct laths of plagioclase and irregular grains of augite and biotite with interstitial grains, some of them roughly poikilitic, of alkalic feldspar and more or less distinct quartz (Pl. XIV, *A*). In others—for instance, from the summit of Sunrise Peak and close to the Horseshoe Hill contact—the groundmass is composed of small plagioclase laths with some augite and biotite in a brown glassy matrix, a texture identical with that in sections from near-by hills in the effusive area (Pl. XIV, *B*). Thus, while the megascopic transition from intrusive monzonite to clearly effusive latite is found at a considerable distance from Sunrise Peak, the microscopic transition takes place within the upper part of the peak itself. Augite is more conspicuous than biotite in the groundmass, though the reverse is true of the phenocrysts, and evidently crystallized as a whole later than the biotite. Alteration of the groundmass to epidote, chlorite, sericite, calcite, and secondary quartz, or chalcedony, is very common.

Specimens from the area of effusive rocks are, as already stated, in large part essentially of the same character as those from Sunrise Peak, but certain differences, especially in color and degree of weathering, are widespread. Though the fresh rock is dark gray, the outcrops have on weathering, which has been more pronounced than at Sunrise Peak, acquired purple or reddish colors. Where brecciated and flow structure is well developed the rock is much more weathered than where it is massive. In thin section the phenocrysts are similar to those of the Sunrise Peak rock, the plagioclase being near $Ab_{50}An_{50}$ or slightly more sodic. Augite is scarce or absent, but as a rule its typical alteration products and crystal outline are recognizable. The groundmass in specimens collected near Sunrise Peak—for example, east of Crystal Canyon and on the ridge northwest of Dry Canyon near the 7,300-foot contour—is identical with that at the summit of Sunrise Peak (Pl. XV, *A*). In specimens collected (during the earlier survey) at greater distances—for example, northeast of Diamond Divide and at the north end of the main latite-andesite ridge—the groundmass is more highly vitreous and shows marked microscopic flow structure and more or less perlitic cracking, and there are relatively few phenocrysts.

OTHER MEMBERS OF THE LATITE-ANDESITE SERIES.

VARIETIES AND DISTRIBUTION.

Other members of the latite-andesite series, which according to the earlier report[1] cover the greater part of the area, include the following varieties: Augite-hypersthene, augite-hypersthene-biotite, hornblende-augite, hornblende-biotite-augite-hypersthene, and hornblende-biotite-augite. Their distribution and extent have not been definitely worked out, but specimens from different localities arranged according to composition show the following groupings:

Occurrence of varieties of latite-andesite in Tintic district.

	Volcano Ridge and Sunrise Peak.	Tintic Mountain and vicinity.	Diamond Divide and vicinity.	Slate Canyon and vicinity.	East of Long Ridge.	Laguna.
Hornblende-augite	....	....	....	....	×	....
Hornblende-biotite-augite	....	....	....	....	×	×
Augite-hypersthene	....	×	×	×	×	....
Augite-hypersthene-biotite	....	×	×	....	....	....
Biotite-augite (Sunrise Peak type)	×	×	×	×	×	....
Augite	×	×	×	×	×	....
Tuff and agglomerate	×	×	×	×	×	×

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 639.

Although it is very probable that there may be more than one flow of the same mineral composition and that some flows were erupted from different centers than others, and although nothing definite is known of the succession of the flows at these different places, the foregoing table is of interest in suggesting a means of correlation which may help toward the further identification of postvolcanic faults.

LITHOLOGY.

The following brief notes will serve to summarize the important characteristics of the different varieties. They are, with one exception, based on study of thin sections made for the earlier report.

Augite-hypersthene-biotite variety.—The plagioclase shows a marked zonal growth and has the average composition of basic labradorite, ranging from bytownite ($Ab_{20}An_{80}$) to basic oligoclase ($Ab_{70}An_{30}$). The augite has the same properties as that in the lavas already described, including a pale-green to yellowish pleochroism. It grades from prisms 2 or more millimeters long down to minute anhedrons in the groundmass. Hypersthene varies in quantity. In some sections it forms a few scattered crystals; in others it is quite as prominent as the augite. It occurs in short, stout prisms, mostly 1 millimeter or less in length, and has a marked pleochroism from pale brownish red to colorless. Biotite, magnetite, and apatite present the same features as in all the other volcanic rocks of the district. The groundmass ranges from minutely holocrystalline to glassy but in all sections is of typical effusive character. A chemical analysis of a specimen of this variety collected on Tintic Mountain and said in the earlier report [1] to represent "a type very important areally and belonging to the latest eruption" is given on page 67.

Hornblende-biotite-augite variety.—The hornblende-biotite-augite variety was found by the writer in the northern part of the area, where it occurs as an extensive flow north and south of Laguna station and as a dike cutting rhyolite about a mile southeast of Pinyon Peak. The flow overlies coarse latite agglomerate and tuff, which in turn rest upon the Packard rhyolite, but no relations with any of the other latite flows were found. The dike is exposed in a railroad cut, where its width is about 100 feet, but is concealed within a short distance on each side of the cut. It is accompanied by a considerable amount of red opaline silica, mostly in the form of loose débris. The only other known occurrence of this variety of latite, as shown in the table on page 61, lies east of Long Ridge, along the southern half of the east edge of the quadrangle. The dike may have served as a feeder to the Laguna flow, although it may be rather too remote from Long Ridge to have supplied the flow there. In any case it seems evident that the flows of this type, like the tuffs beneath them, were erupted from another center than those represented by Volcano Ridge and Sunrise Peak or by the monzonite mass of Silver City.

The rock is medium gray, dense, and porphyritic, with phenocrysts of doubly twinned glassy plagioclase as much as 5 and even 10 millimeters long, black, shiny hornblende in prisms from 2 to 4 millimeters long, and biotite in well-defined six-sided plates 3 millimeters or less in diameter. Biotite and hornblende are about equally abundant. In thin section the plagioclase is zonal and shows the same variation in composition of the zones as in the other varieties. Its average composition, therefore, is that of labradorite. The hornblende is the brown basaltic variety. All its grains show partial to complete resorption, and in a few sections the resorption rims can distinctly be made out to consist of augite in short rods and magnetite or ilmenite in fine rounded grains, both embedded in a matrix of small plagioclase anhedrons. This association tends to show that, in spite of the mineralogic difference, the hornblendic rock is chemically the same as the more common hornblende-free varieties. The biotite is typical. Neither hornblende nor biotite is represented in the groundmass, and their place is taken by augite, which is a prominent microscopic constituent but occurs in poorly formed grains all less than 0.5 millimeter long and grading down to the finest specks. Magnetite and apatite are relatively abundant and large, some attaining a diameter or length of nearly 1 millimeter. Titanite forms a few small microphenocrysts, some of which have perfect crystal outlines. The groundmass is more or less glassy and in other respects typical.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 641.

A partial chemical analysis of this rock and the corresponding partial norm are given below, together with the corresponding percentages in the average latite and average andesite.

Partial analysis and norm of hornblende-biotite-augite latite and analyses of average latite and andesite.

	Analyses.			Norm of No. 1.	
	1	2	3		
SiO_2...	57.27	57.65	59.59	Excess silica......	8.52
MgO...	2.45	3.22	2.75	Orthoclase........	18.90
CaO...	6.06	5.74	5.80	Albite............	24.63
Na_2O..	2.94	3.59	3.58	Anorthite.........	30.02
K_2O...	3.23	4.39	2.04	Magnesium metasilicate..........	6.10
	71.95	....	....		88.17

1. Hornblende-biotite-augite latite. George Steiger, analyst.
2. Aerage latite. Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 221, 1910.
3. Average andesite. Daly, R. A., op. cit., p. 223.

The ratio of potash to soda shown by this analysis is not quite as high as in the other analyses of local latite and monzonite given on pages 56 and 67, and the ratio of normative orthoclase to albite is correspondingly low, but not as low as the true ratio, for a considerable amount of the potash belongs to biotite. These facts, as well as a comparison with the average analyses of latite and andesite, indicate a rock of prevailing latitic character but grading toward andesite. The total alkalies and alkaline earths shown in column 1 are lower than in the other local latite and monzonite, and this deficiency is doubtless compensated by a relatively high percentage of iron, contained chiefly in the basaltic hornblende. A considerable amount of the normative anorthite and a small amount of the albite should be assigned to this hornblende, leaving a higher percentage of albite than is indicated by the optical properties of the plagioclase. This excess of normative albite, as in the augite latite (p. 56), may indicate in part a more sodic variety of plagioclase in the groundmass and soda in the glassy groundmass available for sodic orthoclase. The percentage of silica is very close to that in the average analysis of latite and is sufficient to suggest a small excess over that necessary to form the silicates of the rock. The excess of silica in the partial norm of course includes some that belongs to the iron-bearing silicate minerals.

Hornblende-augite variety.—The hornblende-augite variety is of the same general composition as the rock last described, with the omission of the biotite. The augite, however, in some of the thin sections studied forms more distinctive phenocrysts.

COMPARISON OF THE DIFFERENT VARIETIES.

So far as the microscopic study and partial analyses show, the different varieties of the latite-andesite series are nearly all chemically identical and equivalent to the intrusive monzonitic bodies. This relation is further considered in the description of the monzonite of the Silver City stock. Mineralogic differences, such as the presence or absence of biotite or basaltic hornblende, are evidently due to varying conditions of temperature and pressure when the phenocrysts were forming, or to slight variations in certain constituents, such as iron oxides. The fact that the phenocrysts are generally resorbed is proof that they crystallized before eruption, and that under the different conditions existing during eruption, such as cooling and relief of pressure with liberation of gases, they began to break down into simpler compounds. The two pyroxenes appear stable under the conditions of eruption. The hypersthene, so far as the thin sections studied show, is absent where biotite or basaltic hornblende is abundant (in the augite-hypersthene-biotite variety the biotite is scarce and partly resorbed), and it may be that the presence of hypersthene in some flows accounts for the MgO and some FeO which in other flows is taken by the hornblende and biotite. The presence or absence of hypersthene, however, depends on so small an excess of (Mg,Fe)O over the ratio (Mg,Fe)O:CaO in the diopside molecule of augite that this apparent relation between hypersthene and basaltic hornblende plus biotite must be regarded as only a suggestion.

ALTERATION PRODUCTS.

Alteration products are the same for all the varieties and are generally similar to those in the monzonite porphyry of Sunrise Peak.

MONZONITE (SILVER CITY STOCK).[1]

DISTRIBUTION AND STRUCTURAL RELATIONS.

The latest known important eruption in the district is represented by the Silver City stock of monzonite, the main body of which occupies a considerable area between Mammoth and Silver City and a small area farther south, on the other side of Ruby Hollow, beyond which its southwestward extent is hidden beneath alluvium. A smaller body is exposed northeast of the main one, between Sioux Pass and the Northern Spy shaft, and a few still smaller bodies of dikelike and irregular forms crop out farther northeast. The main body is bounded on the west by alluvium and by the Swansea rhyolite, on the north by the alluvium of Mammoth Basin, on the northeast by contact-metamorphic limestone, and on the east and southeast by the monzonite-latite porphyry from the Sunrise Peak vent and the obscure area of latite tuff.

The contact with the Swansea rhyolite is described on page 50, where evidence is given to show that the monzonite is the younger rock. The contact with the limestone is clearly intrusive, as shown by the several inclusions, the metamorphosed condition of the limestone, the short, irregular apophyses penetrating the limestone, and the tendency of the monzonite to form a narrow porphyritic contact zone. The chilling effects are well shown at Diamond Pass in a northward-trending dike, which has a distinctly granular appearance where it crosses the road but a dense porphyritic texture near its termination along the Black Jack iron mine. The numerous limestone inclusions and the highly disintegrated character of both monzonite and limestone greatly obscure the contact relations east and southeast of Diamond Pass. Several limestone inclusions, once wholly covered by monzonite talus, are now exposed by artificial road cuts and tunnels, and it is very probable that the inclusions are far more numerous than the map indicates.

The contact of the monzonite with the monzonite-latite porphyry is wholly obscured by thorough disintegration and alteration of both rocks and to judge by surface appearances could be interpreted as a gradation, but it is shown elsewhere (p. 58) that the two rocks were erupted at different, though not necessarily widely separated times. The presence of a dike of the monzonite cutting the monzonite porphyry in a railroad cut southeast of Sioux Pass (see Pl. IV, in pocket; also p. 59) is evidence that the monzonite is the younger of the two.

The dimensions of the monzonite, so far as indicated on the surface and in mine workings, are those of a rectangular or elliptical body, only a part of which is exposed. Its northeasterly trend is expressed by the limits of the metamorphic limestone and by the small monzonite stock and dikes already mentioned; also by the absence of any monzonite in the workings of the Opex (2,200 feet deep), Emerald (1,100 feet deep), and Mammoth (2,300 feet deep). The arrangement of the limestone inclusions, which are more numerous than is shown on the map, indicates the great irregularity of the upper monzonite contact. The northernmost portion, which in the Lower Mammoth workings is seen pitching northeastward beneath the limestone, is virtually separated from the rest by the large limestone inclusions shown on the map. Only two are mapped, but the tunnel represented as penetrating southward toward Robinson triangulation station is mostly in limestone blocks that lie beneath a surface of monzonite débris and are separated from one another by monzonite. The northeastward continuation of the monzonite beyond these inclusions is expressed by the broad metamorphic limestone zone. East of Diamond Pass the monzonite again rises among numerous limestone blocks, and the highest point along its contact is near the 7,000-foot contour. The small stock at Sioux Pass is even higher, reaching the 7,540-foot contour along its west contact, and may well mark the reappearance of the Diamond Pass "apex" continued through the hill. This relation is further suggested by the distribution of metamorphic limestone. Recent developments on the 800 and 1,000 foot levels of the Dragon iron mine have exposed the contact of monzonite and limestone west and south of the shaft and proved that it extends eastward beneath the surface at this place. (See fig. 9, p. 60.) The absence of typical monzonite, except possibly as a few thoroughly decomposed dikes, in the Northern Spy and Iron Blossom No. 3 workings, together with its absence in the lower area to the northeast and

[1] In the earlier report this monzonite and the monzonite porphyry were mapped as "Sunrise monzonite."

east, proves that the roof of the monzonite body must pitch steeply in these directions. The considerable extent of mild contact metamorphism associated with the small intrusions near Burriston Canyon, however, suggests that a rather large body of monzonite is not many hundred feet below the surface there.

The thickness of cover over the intrusive monzonite must have been considerable. The numerous inclusions of limestone and quartzite show that the path of the intrusion lay mostly through these rocks, and the presence of scattered rounded inclusions of latite or andesite, as well as the character of the eastern contact of the monzonite, indicates that some surface flows may also have capped the area. The maximum thickness of limestone, if the present highest peaks were assumed to represent remnants of a horizontal plateau, would have been about 1,000 feet; but such an assumption is not warranted either by the relative rate of erosion of the limestone or by the character of the prevolcanic topography as shown by the Packard rhyolite contact and the effusive contacts around Sioux Pass. Faulting (see p. 86) might account for a sufficient sedimentary cover over the western edge of the monzonite, but not over its greater part. How great a thickness of volcanic rocks may have once been present here can not be accurately ascertained from their present distribution, but their relatively rapid rate of erosion could account for the disappearance of a considerable thickness. The extension of the latite of Sunrise Peak in this direction, to judge from its distribution, could hardly have reached above the present 7,200 or 7,300 foot contour, but eruptions from the monzonite center itself may well have taken place, including rhyolite from the Swansea intrusion, and built up a thick series of tuffs and lavas. If the uppermost flows of the volcanic series—for example, the augite-hypersthene-biotite latite of Tintic Mountain, which is very similar in composition to the Silver City stock of monzonite—are projected over the monzonite with as low a dip as 5°, they will indicate an approximate thickness of 3,000 feet above the present surface. Such a thickness, even after deduction for possible overestimate, would have formed a cover quite sufficient to account for the slow cooling indicated by the texture of the monzonite and would probably also have completely covered the highest limestone peaks. The great amount of erosion necessary for the complete removal of so thick a series from the entire area north and east of the monzonite throws some doubt upon the relations suggested; but that the postulated erosion is possible is shown in section C–C′ of Plate II, where the restoration of the Volcanic Ridge and Sunrise Peak cones indicate that between 2,000 and 3,000 feet of rock has been removed. The evidence as a whole, therefore, although not actual proof, suggests very strongly that the plutonic character of the monzonite and the great temperature changes expressed in the metamorphic limestone are due to the slow cooling of the monzonite magma under a cover composed in part of sedimentary rocks but mostly of volcanic rocks.

LITHOLOGY OF THE MAIN TYPE.

The color of the freshest material found is a uniform dark, smoky purple, but by far the most common color is a light speckled gray with brownish and pale pinkish variations. The megascopic texture appears to be mostly even granular, with a porphyritic tendency in many places, plagioclase and subordinate hornblende or pyroxene forming the phenocrysts. The megascopic minerals are purple to white plagioclase, in automorphic crystals averaging 3 millimeters in length, with distinct albite twinning, alkalic feldspar, mostly of pale pink color, in aggregates of fine anhedral grains tending to surround plagioclase and the dark minerals; hornblende or pyroxene, in short dark-green prisms 1 to 2 millimeters long, single or here and there in small aggregates, some showing splintery cleavage suggestive of hornblende, others a single smooth cleavage or parting suggestive of pyroxene; biotite, locally in distinct flakes but mostly in obscure specks, decidedly subordinate to the hornblende or pyroxene; magnetite, in minute specks; and in some specimens pyrite, in minute grains or streaks, for the most part distinctly secondary.

In thin section (Pl. XV, *B*, p. 61) the porphyritic character is much more common, owing to the prevailing greater size of the automorphic plagioclase and hornblende or pyroxene over that of unhedral alkalic feldspar and quartz.

The plagioclase, all in automorphic crystals, the shortest 0.1 millimeter long, is twinned according to both Carlsbad and albite laws, and its extinction angles on combined twins indicate a composition of $Ab_{53}An_{47}$, or between $Ab_{55}An_{45}$ and $Ab_{50}An_{50}$. It incloses minute grains of augite and magnetite but is partly surrounded by large grains of the same minerals. It is as a rule free from marked alteration, but where alteration has been locally pronounced it is changed more or less to sericite, epidote, calcite, and quartz. The alkalic feldspar forms xenomorphic grains, few over 1 millimeter in diameter, with some suggestion of perthitic structure. It lies mostly in the groundmass, but some of the larger grains form imperfect borders around plagioclase crystals. It is uniformly dusted with kaolin, in marked contrast to the fresh plagioclase. Quartz is present only as microscopic anhedral grains 0.2 or 0.3 millimeter in diameter, that are abundant in the groundmass and closely associated with the alkalic feldspar, the two forming micrographic intergrowths at many points. In one section almost the whole groundmass was composed of the micrographic intergrowth embedding automorphic crystals of plagioclase and ferromagnesian minerals. Augite forms imperfectly shaped (hypautomorphic) crystals, whose edges interlock with the grains of the groundmass. Most grains show twinning, some simple, others multiple. Pleochroism is very slight or absent. Many crystals are full of small magnetite grains and have outer fringes of poorly developed biotite. Alteration varies; in the small stock north of Sioux Pass the augite has gone over to chlorite (delessite) and calcite, the typical alteration in the effusive rocks, but in the main body most of the augite has altered to hornblende. The latter change can be followed from sections in which the augite shows hardly a trace of alteration, through those in which all but a central core has changed to fibrous, uralitic hornblende, to others, by far the most numerous, in which only fibrous or compact hornblende is present. Some hornblende grains are distinctly eight-sided, evidently preserving the cross-section outline of the original augite. Others form short prisms, roundly or bluntly pointed at the ends, resembling the hypersthene of the effusive rocks; but no unchanged hypersthene was found in any of the monzonite sections. Biotite forms a few typical crystals, rarely over 1 millimeter in diameter, but is mostly limited to small clusters, apparently the arrested growth of larger crystals, around the augite-hornblende and also scattered through the groundmass. Both the augite-hornblende and the biotite may be altered, the former to chlorite with epidote or calcite, the latter to chlorite alone. Magnetite forms irregular grains, rarely as much as 1 millimeter in diameter. It incloses apatite, and small granules of it are inclosed in or intergrown with the ferromagnesian minerals; but the boundaries between it and these minerals are irregular, and in some sections the larger magnetite grains partly surround the corners of augite and plagioclase crystals. In the same sections its outlines against quartz or the micrographic intergrowths are largely but not wholly automorphic. Apatite, zircon, and titanite form typical small to minute crystals, inclosed in all the other minerals.

The original ferromagnesian minerals—augite, possibly hypersthene, and biotite—are noteworthy in their difference in character and relative amounts from those in the monzonite-latite porphyry of Sunrise Peak and their closer similarity to those of later flows, especially the latest latite flow on Tintic Mountain (p. 62). Although not strong evidence in itself, this difference accords with other evidence showing the monzonite of the Silver City stock to be different from and later than the monzonite-latite porphyry of Sunrise Peak.

CHEMICAL COMPOSITION.

The chemical analysis of the monzonite is given in column 1 of the table on page 67. Comparison with column 5 shows the close similarity with the latite of Tintic Mountain. Comparison with column 4, the average analysis of monzonite, shows an excess of silica in the Silver City stock, which accounts for much of the free quartz. The name "quartz monzonite," however, has not been adopted, for quartz is only rarely present in megascopic grains, and "monzonite" therefore seems preferable for field use. The low MgO and CaO as compared with the average analysis indicate a relatively low percentage of dark silicates, a difference in accord with the excess of quartz.

Comparison with analyses of the monzonite at Bingham, Utah (columns 2 and 3), shows a close similarity between the two rocks. The rock of the Tintic district is relatively low in MgO and especially in CaO, but the differences are no greater than may exist in different members of the monzonite-latite series of the Tintic district. The mineral composition of the two rocks is also very similar, though the rock at Bingham shows more variation in the occurrence of the dark silicates.[1] Andesites, near latite in composition, are also present in the Bingham district and have the same relations to prevolcanic topography as the flows at Tintic.[2] The time of intrusion of the monzonite at Bingham is not definitely known. Keith states that it may have been either before or after the folding of the sedimentary rocks, and that "the facts in other regions may throw light on this question." The close similarity in composition and in structure between the two occurrences suggests their correlation as parts of one extensive monzonite magma, which the more complete structural record at Tintic proves to have been intruded long after the folding and during the Tertiary (post-Eocene) volcanic period.

Analyses of monzonites and latites.

	1	2	3	4	5	6	7
SiO_2	59.76	58.64	57.16	55.25	60.17	59.43	57.65
Al_2O_3	15.79	15.35	16.69	16.53	15.78	16.68	16.68
Fe_2O_3	3.77	3.25	3.47	3.03	3.42	2.54	2.29
FeO	3.33	2.54	2.76	4.37	2.95	3.48	4.07
MgO	2.16	3.84	2.47	4.20	2.52	1.84	3.22
CaO	3.88	5.37	5.86	7.19	4.69	4.09	5.58
Na_2O	3.01	3.60	3.82	3.48	2.96	3.72	3.59
K_2O	4.40	4.23	4.49	4.11	4.16	5.04	4.39
H_2O-	.31	.86	.83	.66	.25	.27	.77
H_2O+	1.11	1.50	1.06		1.23	.72	
TiO_2	.87	.83	.87	.60	.87	1.38	1.00
CO_2	.78	None.	None.	....	Undet.	Undet.	.14
P_2O_5	.42	.02	.41	.42	.40	.58	.36
S	Undet.	.05	.02	....	....	....	....
Cr_2O_3	Undet.	Trace.	Trace.	....	....	....	....
MnO	.12	Trace.	Trace.	.15	.11	Trace.	....
BaO	.09	.18	.30	....	.14	.14	.16
SrO	Trace.	Undet.	Undet.	....	.09	Trace.	....
Li_2O	Trace.	Undet.	Undet.	....	Trace.	None.	....
V_2O_3	.02	Undet.	Undet.	....	.01	....	....
Mo	Trace.	Undet.	Undet.	....	....	....	....
Cl	.04	Undet.	Undet.	....	.04	.05	....
ZrO_2	....	....	....	....	....	.08	....
	99.83	100.26	100.21	100.00	99.79	100.01	100.03

1. Monzonite near Iron Duke mine, east of Silver City, Tintic mining district, Utah. H. N. Stokes, analyst. Tower, G. W., jr., and Smith, G. O., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 647, 1898.
2. Monzonite, Tribune tunnel, Bingham mining district, Utah. E. T. Allen, analyst. U. S. Geol. Survey Prof. Paper 38, p. 178, 1905.
3. Monzonite, British tunnel, Bingham mining district, Utah. E. T. Allen, analyst. Idem.
4. Average analysis of monzonite. Daly, R. A., Am. Acad. Arts and Sci. Proc., vol. 45, p. 221, No. 19, 1910.
5. Latite, Tintic Mountain, Utah. H. N. Stokes, analyst. Tower, G. W., jr., and Smith, G. O., op. cit., p. 649.
6. Augite latite. Dardanelle flow, Cal. H. N. Stokes, analyst. U. S. Geol. Survey Bull. 89, p. 58, 1898.
7. Average analysis of latite. Daly, R. A., op. cit., p. 221, No. 20.

MINOR VARIATIONS.

Four interesting minor variations of the monzonite were noted and are briefly described below. These are the normal contact porphyry, a quartz porphyry, an alkalic granite, and a syenitic porphyry containing aegirite-augite.

Contact porphyry.—The normal contact porphyry is of very small extent, and has been found only locally. It is perhaps best exposed at Diamond Pass, at scattered points on the upper road, and along the crest of the southward-trending spur. It is dark gray, dense, and slightly porphyritic. The only conspicuous phenocrysts are plagioclase; they are smaller and far less numerous than in the porphyry of Sunrise Peak. In thin section the texture is rather uneven, the phenocrysts tending to seg-

[1] Keith, Arthur, Areal geology [of the Bingham mining district, Utah]: U. S. Geol. Survey Prof. Paper 38, p. 51, 1905.
[2] Idem, p. 55.

regate and form patches of coarser grain. The most abundant phenocrysts seen in the thin section are plagioclase, which is zonal, the composition of different zones ranging from $Ab_{40}An_{60}$ to $Ab_{85}An_{15}$ and averaging about $Ab_{50}An_{50}$. Augite forms a few small crystals of the same character as in the main type. A few scattered grains of weakly pleochroic hornblende are also present. Biotite forms a few skeleton-like flakes, some mingled with augite, others separate. The groundmass is composed of fine plagioclase laths with interstitial ferromagnesian minerals, alkalic feldspar, and quartz.

Quartz porphyry.—The quartz porphyry phase of the monzonite forms a rim around the large impure quartzite inclusion in the sag northwest of the Robinson triangulation station. It grades into typical monzonite. Its megascopic appearance is essentially the same as that of the Swansea rhyolite porphyry, save that the phenocrysts are smaller. In thin section the phenocrysts are poorly formed and include both of the feldspars, quartz, and hornblende (probably after augite). The groundmass is very fine grained and highly quartzose. The one section studied was too poor to warrant a more detailed description, but the evidence presented shows that the quartz porphyry phase is intermediate in character between the Swansea rhyolite porphyry and the monzonite, and at least suggests a small amount of marginal assimilation, the impure quartzite having enriched the monzonite magma in silica, a little alumina, and probably a little potash. These additions would cause an increase in the percentages of quartz and probably alkalic feldspar, which in turn could account for the appearance of these minerals as phenocrysts.

Time was not taken to study the margins of all the quartzite inclusions, and it is not known whether such quartz porphyry rims are common or exceptional. In either case, however, the occurrence is of interest as a suggestion of the reactions that may result where a monzonite remains for a long time in contact with quartzite or other highly siliceous rocks.

Alkalic granite.—The alkalic granite phase was found as a segregation about 1 foot in diameter in a small prospect hole nearly 600 feet due south of the road fork at Diamond Pass. It is light gray, fine and even grained, and composed almost entirely of unstriated feldspar and quartz, with thinly scattered indeterminable black grains. In thin section it is composed of microperthite about 64 per cent, quartz about 34 per cent, and plagioclase, slightly pleochroic augite (and hornblende), magnetite, and zircon. The microperthite forms hypautomorphic interlocking grains, considerably kaolinized, as in the typical monzonite. The quartz as a whole is interstitial, but its contacts are much intergrown with the feldspar.

The rock is interesting when compared with the typical monzonite as a product of simple differentiation by fractional crystallization. The fact that the alkalic feldspar and quartz are confined to the groundmass in the porphyritic phases of the monzonite is evidence that they were the last important minerals of the rock to crystallize. If the other minerals after crystallizing had time to segregate and form a local body unusually rich in plagioclase and augite—in other words, a gabbro—they would leave the remaining fluid portion to crystallize as alkalic granite. Such residual portions of alkalic granite could form local patches grading into the surrounding rock, as in the present case, or might remain fluid until fracturing of the already solidified inclosing rock allowed them to take the form of local dikes.

A few narrow dikelets of granitic composition were found near the Swansea rhyolite contact. One cut across a latite dike, which in turn cut both the rhyolite and the monzonite. The texture of the granitic dikelets ranges from aplitic to finely pegmatitic, with margins of feldspar and middle bands of quartz and fine black grains. As seen under a hand lens the pink alkalic feldspar predominates over the fine grains of white plagioclase. The origin of these dikelets may be closely similar to that of the alkalic granite just described, the residual alkalic magma having been tapped by a fracture in the already consolidated monzonite. The percentage of plagioclase in such a rock could vary according to the completeness of separation before consolidation, with or without local intrusion.

Syenitic porphyry.—The syenitic porphyry phase was found near the west margin of the small stock north of Sioux Pass, within a few feet of its highest point. As its differences from the normal porphyry phase are microscopic, its extent can not be more definitely stated. It is dark gray and ranges in texture from a typical porphyry to a completely

granular rock that grades into typical monzonite. The phenocrysts are plagioclase in well-formed laths and small irregular pitchy black grains, which the microscope proves to be aegirite-augite. In thin section (Pl. XVI, *A*, p. 78), the plagioclase is zonal and the zones range in composition from labradorite in the central part to oligoclase ($Ab_{80}An_{20}$) on the rim. The plagioclase crystals are partly or even wholly surrounded by microperthite crowded with minute grains of aegirite-augite. The microperthite and aegirite-augite form small phenocrysts, rarely over 1 millimeter long, which grade down to granules in the groundmass. The groundmass is composed essentially of alkalic feldspar and aegirite-augite, with numerous small grains of titanite and a few of epidote. The character of both titanite and epidote and especially their intimate relations with unaltered microperthite and aegirite-augite suggest their primary origin. Magnetite, apatite, and zircon are also present in small amount. In one or two places phenocrysts of plagioclase have been fractured and recemented by veinlets of microperthite and aegirite-augite.

The textural relations of the minerals show the rock to be virtually a groundmass of alkalic syenite with inclosed plagioclase crystals of the same composition as those which characterize the monzonite—evidently a product of incomplete differentiation. The adjacent monzonite is of the main type, containing nonpleochroic augite and considerable quartz. The process of differentiation, therefore, was not so simple as in the other phases described. The porphyry has lost its excess silica and increased its alkalies. More thorough study may show it to be the result of reaction between the monzonite and the inclosing dolomite, as suggested by Daly.[1] The unusual abundance of titanite along with the epidote may be attributed to the union of lime from the dolomite with some of the excess silica of the monzonite. The position of the porphyry at the very highest part of the contact, or at the very roof of the stock, is also favorable to Daly's hypothesis.

MONZONITE PORPHYRY DIKES.

Dikes of monzonite porphyry have been found at a few places but can not be certainly correlated with any of the large occurrences, intrusive or effusive. One dike, about 8 or 10 feet thick and of easterly trend, cuts the main monzonite mass in a railroad cut west of the road forks in Dragon Canyon. Its mineral composition is the same as that of the inclosing monzonite. The narrow latite dike of northerly trend, cutting across the monzonite and quartz porphyry contact, is mentioned on page 68. It is almost nonporphyritic, but its microscopic mineral composition is similar to that of the monzonite. A few dikes, one as much as 100 feet wide, cut the effusive lavas just east of Sunrise Peak. They are weathered to a greenish-gray color and have a finely granular groundmass. They are much altered but are similar to the main monzonite mass in mineral composition and may have been feeders to some of the upper flows of pyroxene latite.

Two obscure occurrences were found in the vicinity of Burriston Canyon—one to the south, near the east end of the earlier rhyolite, and one to the north, on the southward-sloping limestone spur. The exposures were too badly disintegrated to show their structural relations clearly, but both are intrusive and associated with marbleized limestone. (See p. 65.) The unaltered rock is of light-gray to brownish color, unlike any of the other dikes. The phenocrysts are plagioclase, somewhat less calcic than in the other monzonite rocks, biotite in well-formed abundant crystals, and microscopic augite. The groundmass is distinctly quartzose and resembles that of microgranite, but the rock contains no phenocrysts of quartz. Its general character, however, though intermediate, is nearer to that of monzonite than to that of the rhyolites of the district.

OLIVINE BASALT.

No basalt exposures were visited during the recent survey, and the following paragraphs are quoted from the earlier report:[2]

> Although basalt is of common occurrence south of the Tintic Mountains, as well as in the other parts of the Great Basin, it was found in only one locality within the Tintic quadrangle. House Butte is a prominent flat-topped hill about 1 mile west of Tintic Mountain. Basalt occurs here in three small areas, the outlines of which suggest intruded sheets. Immediately southeast of House Butte basalt is found on the side of a ravine. In these localities, as elsewhere in the Tintic Mountains, talus accumulations somewhat conceal geologic relations.
>
> Megascopically the basalt is a black, very compact rock, without the vitreous texture of the darker of the

[1] Daly, R. A., Origin of the alkaline rocks: Geol. Soc. America Bull., vol. 21, pp. 87-118, 1910.

[2] Tower, G. W., jr., Smith, G. O., op. cit., p. 648.

andesites (latites). It is very fine grained, and no megascopic phenocrysts occur. Under the microscope the only phenocrysts seen are of olivine and augite, and these are much less important in amount than the groundmass. The olivine occurs in well-terminated prisms and appears quite free from alteration. The augite is also colorless in the thin section but is readily distinguished from the olivine by its more perfect cleavage and inclined extinction.

The groundmass of the basalt is quite holocrystalline, consisting of a uniform mat of laths of plagioclase feldspar and crystals and anhedra of augite. Magnetite in small crystals and grains is scattered throughout the rock, while apatite occurs in long microscopic needles. The microlites of feldspar show a distinct flowage around the phenocrysts. Calcite and a yellowish-brown material fill pores in the rock.

DIFFERENTIATION OF THE IGNEOUS ROCKS.

ESTABLISHED FACTS.

A complete discussion of magmatic differentiation of the igneous rocks of the Tintic district, although many facts have been established, must involve considerable speculation on factors whose influence is unknown. The more of these indefinite factors there are the farther must the discussion come from reaching a convincing conclusion. Any treatment of the subject should recognize the possible influences of magmatic stoping and abyssal assimilation on physical and chemical conditions within the magma. The conclusion is reached that the siliceous rocks of pre-Cambrian and possibly Cambrian age may perhaps have contributed material to the formation of the rhyolites, but that the limestones had no appreciable influence of any kind on the composition of the igneous rocks now exposed.

The established facts are summarized below.

1. The sedimentary rocks, all older than the igneous, had been folded and, as shown in a subsequent section (pp. 77–90), extensively faulted before volcanic eruptions began. Some faults, however, especially around the monzonite, were evidently formed during volcanic activity.

2. The prevolcanic topography of the sedimentary area was much the same as that of to-day, and postvolcanic erosion has been confined mostly to the volcanic rocks, which in some places may have been as much as 3,000 feet thicker than now.

3. The known order of eruption is (1) latite or andesite, (2) rhyolites, (3) latite and monzonite, (4) basalt.

4. These rocks are closely related in mineral and chemical composition, as well as in geologic occurrence, and, with the possible exception of the basalt, evidently came from a common source. It is possible that the small amount of basalt is much later than the other rocks and came from a deeper source. It may be equivalent to the basalts elsewhere in Utah that were erupted in late Tertiary and early Pleistocene time, after the uplift of the immense fault blocks of the "Basin Ranges."

5. The order of crystallization in all the rocks has been the same—(1) plagioclase (in crystals with successively less calcic zones), ferromagnesian silicates, magnetite, apatite, and zircon; (2) alkalic feldspar and quartz (if present). The exact order for single minerals can not be definitely stated, but the first group as a whole was distinctly earlier than the second. The quartz phenocrysts in rhyolites were later than the phenocrysts of the first group, so far as direct relations between them could be found.

Among the indefinite factors are these:

1. The rocks cut by the uprising magma in the different volcanic centers include, besides a measurable thickness of limestones, a thickness of quartzite indefinitely greater than 6,000 feet and an unknown thickness of pre-Cambrian granites, gneisses, quartzites, and schists which are known to underlie the quartzite elsewhere in Utah.

2. The fact that the dimensions of the igneous rock bodies beneath the surface are unknown prevents even an approximate estimate of the volume of pre-Cambrian and Cambrian rocks displaced and thus rendered subject to sinking and to abyssal assimilation.

3. The duration of volcanic activity and the time available for the assimilation of older rocks and for differentiation of the resulting syntectic magma which could be expressed in the later eruptions are likewise unknown.

4. There are no data available as to the shape of the roof of the magma reservoir and the homogeneity of the magma at the beginning of the volcanic period. The roof may have been sufficiently irregular for the rhyolitic portions of the magma to collect in the uppermost parts of the chamber through gravitative differentiation, even before any eruptions took place.

EVIDENCE IN EARLY LATITE AND EARLY RHYOLITE.

The oldest volcanic rock found by the writer is the early latite or andesite, but whether this rock is the oldest of the entire volcanic series is not known. Furthermore, it is not known through what conduit or conduits this latite and the succeeding early rhyolite were erupted, nor through how many geologic formations the conduits extended. If any rocks displaced in the lower and probably larger part of the conduit sank and were assimilated by the magma, the rocks thus assimilated must have included the siliceous pre-Cambrian rocks and perhaps some of the Tintic quartzite, but limestone could have played only a minor part in the process. Whether or not assimilation of these rocks was influential in giving the oldest of the known lavas of the Tintic district a latitic composition can not be determined without a knowledge of the composition of the original magma.

Comparison between the visible mineral composition of the early andesite or latite and that of the early rhyolite suggests a differentiation of the latite magma without any necessary addition of assimilated rock, but the impossibility of determining the primary silica in either rock prevents a definite conclusion on this point. If, after the first latite eruption, the magma remained in the conduit at the general crystallization point for the first group of minerals (calcic plagioclase and ferromagnesian silicates), the crystallization of these minerals and the gradual settling of their crystals [1] with a simultaneous rising of the still fluid material would leave in the upper part of the conduit a residual magma composed principally of the constituents of alkalic feldspar (including the more sodic end of the plagioclase series), with any excess of silica. In other words, a trachyte or rhyolite would be the next lava erupted.

Such a separation of alkalic from subalkalic magma is illustrated on a small scale by the small alkalic granite segregation in the monzonite, described on page 68. What has thus taken place on a small scale near a chilled upper contact may have taken place on a large scale in a standing column of liquid lava covered by hot, newly consolidated rock. The degree of separation depends upon the length of time in which the lava column can remain at or below the crystallization points of the more calcic plagioclase and ferromagnesian (mafic) minerals and above those of alkalic feldspar (and quartz). That such an interval may be of considerable duration is shown by the latites of the district—for example, that of Tintic Mountain (p. 62), which is composed of more or less resorbed phenocrysts of plagioclase and mafic minerals, in a glassy groundmass made up chiefly of the components of alkalic feldspar and quartz.

EVIDENCE IN THE PACKARD AND SWANSEA RHYOLITES.

The chemical relations between the Packard and Swansea rhyolites and monzonitic rocks are illustrated by analyses. The relations of both these rocks to the sedimentary rocks, however, though rather clearly shown structurally, leave room for speculation so far as assimilation of sediments and subsequent differentiation are concerned.

RELATIONS TO MONZONITIC ROCKS.

The chemical and mineral differences between these rhyolites and the monzonitic rocks are shown by a comparison of their norms: [2]

Norms of rocks of Tintic district.

	Swansea rhyolite.	Packard rhyolite.	Latite of Tintic Mountain.	Monzonite of Silver City.
Quartz	34.2	24.0	13.6	14.6
Orthoclase	26.1	30.0	25.0	26.1
Albite	25.2	30.0	25.2	21.1
Anorthite	5.8	8.1	17.0	16.7
Corundum	2.5	.0	.0	.0
Diopside	.0	1.1	5.3	2.4
Hypersthene	1.1	1.3	5.0	5.8
Magnetite	....	....	4.9	5.6
Ilmenite	....	1.2	1.7	....
Hematite	.9	2.5	....	....
Pyrite	2.3	.0	....	....

[1] The hypothesis of such gravitative differentiation has been advocated by a number of writers who differ from one another regarding certain details according to their respective conceptions of intratelluric conditions. So far as the present writer's explanation is concerned, it does not matter whether the process was one of a simple fractional crystallization or involved more or less redissolving of the sinking crystals, so long as it was of sufficient duration to have formed the quantity of rhyolite known to have been erupted in the area. For general discussion of the question of differentiation appropriate to the present case, see Schweig, M., Differentiation der Magmen: Neues Jahrb., Beilage Band 17, p. 516, 1903; Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Mont.: U. S. Geol. Survey Bull. 237, pp. 181-197, 1905; Iddings, J. P., Igneous rocks, vol. I, pp. 287-295, 1909; Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 307, 313, 1916; Bowen, N. L., The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, suppl., 1915.

[2] Washington, H. S., op. cit., pp. 183, 391.

The two rhyolites have about twice as much normative quartz as the latite and monzonite. The two normative alkalic feldspars maintain a nearly uniform ratio throughout. Those in the Packard rhyolite are in excess of the others but still maintain the ratio 1:1. The anorthite of the norm is more indefinite, as much of this molecule in the latite and monzonite actually belongs to augite or hornblende. The true variation in the anorthite molecule is better shown by the optical determination of plagioclase in the four rocks—respectively $Ab_{65}An_{35}$, $Ab_{65}An_{35}$, $Ab_{70}An_{30}$, and $Ab_{40}An_{60}$—and shows a tendency for anorthite to diminish as quartz increases. As biotite is only a minor mineral in all the four rocks, the excess of diopside and hypersthene in the monzonite and latite serves to express, along with a part of the normative anorthite, the amount of pyroxene and hornblende present.

The nearly uniform ratio of the orthoclase and albite molecules confirm geologic evidence pointing to the close genetic relation of the several rocks. Differentiation must have taken place mostly before crystallization or during its early stages, as is shown by the varying composition of the plagioclase. The process, involving a concentration of SiO_2 in one direction and a complementary concentration of Fe_2O_3, FeO, MgO, and CaO in the other, produced two magmas of different specific gravity. The supposition that the lighter, rhyolitic fraction rose to the top of the magma chamber and was the first to be erupted agrees with the field evidence. Calcic plagioclase (preserved as the inner zones of the crystals in the latites and andesites), biotite, brown hornblende, and augite crystals were the first to form, as shown by the textures of all the rocks of the district. The crystallization and settling of these minerals and an accompanying rise of materials that were still above their crystallization points left at the top of the chamber a magma composed essentially of the constituents of alkalic feldspar, the more sodic plagioclase, and quartz.

Had this separation progressed to completion, practically all the anorthite fraction of plagioclase and nearly all the mafic constituents would have been removed downward, leaving an upper portion with the composition of alkalic granite or rhyolite (alaskose or liparose); but volcanic activity was resumed before the separation was completed, and the upper magma, still containing enough of the anorthite molecule to form andesine, was erupted through two or more different vents to form the rhyolites. The small differences in composition between the Packard and Swansea rhyolites may be attributed to slight differences in the elimination of anorthite and femic molecules at two different vents, but the differences are too slight to be of any real significance. The quartz and alkalic feldspar in the monzonite may also signify incomplete differentiation.

RELATIONS TO SEDIMENTARY ROCKS.

Whether this differentiation was due to the separation of constituents of the original magma or of a syntectic magma formed by the assimilation of sedimentary rocks will now be considered. Marginal assimilation on a small scale is suggested on page 68, in the description of a rhyolitic border around a quartzite inclusion in monzonite. If marginal assimilation on a small scale is possible, it is also possible that, during the indefinite time that preceded the concentration and eruption of rhyolite, the unknown thicknesses of pre-Cambrian rocks and possibly the lowest beds of the Tintic quartzite may have undergone extensive assimilation, enriching the magma in silica and to some extent in alkalies and other constituents.

The evidence, however, so far as the rhyolites are concerned, is very obscure. The top of the Packard Peak conduit must be in rock at least as young as Ordovician and probably as young as Mississippian (Pl. I). The conduit may be of cylindrical form, as suggested in Plate II, section A–A′, or the lava may have issued from fissures now occupied by dikes. A cylindrical conduit could have been formed in part by the stoping of the country rock, but it may have been due largely to the thrusting apart of the inclosing rocks, as suggested by the faults west of Packard Peak. It is therefore improbable that any great quantity of limestone was carried to abyssal depths and dissolved in the magma.

It is conceivable that, prior to the rhyolite eruption, a monzonitic magma was intruded into the thick mass of unexposed pre-Cambrian rocks and even into the lower beds of the Tintic quartzite, which in this vicinity are over 2 miles below the vent. A magma at such depths may well have remained liquid long

enough to have stoped and dissolved a considerable amount of siliceous rock and to have subsequently yielded the rhyolite by differentiation. Whether or not blocks of quartzite could sink in a monzonite magma is discussed on page 87.

Evidence is equally inconclusive with regard to the Swansea rhyolite. It passed upward at least as far as the Cole Canyon dolomite (Pl. IV), and the opportunities for speculation on deep-seated magmatic processes prior to its eruption are essentially the same as those suggested by the Packard rhyolite.

EVIDENCE IN THE LATITES AND MONZONITE.

The latites in the tuff cone of Volcano Ridge must have risen for most of their course through a conduit in quartzite and older rocks, and whatever limestone may have sunk in the conduit prior to explosive eruptions could not have been sufficient to affect the composition of the magma materially. The processes suggested as possible in the Packard Peak conduit may therefore have taken place here also. As the tuffs and dikes are clearly later than the Fernow rhyolite, which is exposed in the vicinity, it may be inferred that after the more siliceous rhyolitic fraction had been erupted from the top of the magma chamber an underlying less siliceous fraction, in part represented by the augite latite (p. 56), furnished the material for the next eruptions.

The upper part of the monzonite porphyry plug of Sunrise Peak cuts the tuff cone just considered and below this must pass through an unknown thickness of quartzite and limestone. As the monzonite porphyry and its corresponding latite are similar in microscopic mineral composition to inclusions in the tuff, no pronounced differentiation of the magma can have taken place between the eruption of Volcano Ridge and that of Sunrise Peak, and therefore no assimilation of quartzite or limestone blocks can have seriously affected the composition of the magma.

The monzonite, the latest intrusive of any importance in the district, worked its way upward chiefly through quartzite and limestone and in part through the Swansea rhyolite. Its method of intrusion, as shown in the discussion of faulting (pp. 87–88), consisted to a considerable extent in the thrusting upward and aside of large blocks of sedimentary rocks and of the Swansea rhyolite. These blocks, after being faulted, were partly removed by the stoping process, as is shown by the many inclusions of limestone and quartzite in the monzonite; but as these inclusions have not sunk any great distance from their original positions, there was probably little or no assimilation of them. As the most noteworthy change in composition of the magma between the eruption of the Swansea rhyolite and that of the monzonite was a diminution of silica, the stoping of siliceous rock at great depth prior to the faulting due to intrusion can have had no marked influence on differentiation.

The relations of the monzonite to limestone require special discussion in view of Daly's hypothesis that monzonites and alkalic igneous rocks owe their origin to differentiation from subalkaline magmas following the assimilation of limestones.[1]

A rough idea of the volume of limestone displaced by the main monzonite mass can be gained by noting the contacts in the Lower Mammoth and Dragon mine workings and by estimating the volume of the formations represented in the metamorphic limestone area; but the numerous large inclusions of limestone in the monzonite, as already shown, did not have time to affect the composition of the magma appreciably. The small monzonite stock north of Sioux Pass, however, cut its way at least through the Bluebell dolomite and, to judge from its granular texture, probably extended for a considerable distance higher. Its underground dimensions are not known, but the evidence cited on page 64 indicates a very steep downward divergence of its boundaries. The total stratigraphic thickness of limestone displaced by this stock is at least 4,300 feet, and the entire volume of limestone displaced by monzonite must be very great; but, as will be shown presently, it does not seem probable that the displaced limestone appreciably affected the composition of the magma through assimilation.

The possibility must be considered that magma of rhyolitic composition may originally have been in contact with the limestones and remained there long enough to become desilicated through reaction with limestone inclu-

[1] Daly, R. A., Origin of alkaline rocks: Geol. Soc. America Bull., vol. 21, pp. 87-118, 1910.

sions. One volume of pure dolomite would raise the lime and magnesia in 10 volumes of Swansea rhyolite approximately to their percentages in the monzonite of Silver City. One volume each of dolomite and limestone (according to the thicknesses and composition of the Tintic rocks the volume of displaced limestone must equal or exceed that of displaced dolomite) would raise the lime in 25 volumes of rhyolite to more than the quantity in the monzonite but would make up only half the difference between the magnesia percentages of the two rocks. Some further concentrations within the magma must then be postulated to account for the percentages of lime and magnesia in the monzonite, as well as for the increase instead of decrease in iron oxides and for so great a decrease in silica (from 71.5 to 60 instead of 66.7 per cent); but such concentrations would imply time for gravitative differentiation, or the sinking of the ferromagnesian minerals and calcic plagioclase, which would unmake rather than make magma having the composition of the local monzonite.

An equally serious if not more serious objection to such an origin for the monzonite is based on geologic grounds. For so great a body of rhyolitic (or granitic) magma to remain fluid long enough to allow for such assimilation and differentiation implies batholithic, or at least hypabyssal, conditions; but it has been shown that the topography of the sedimentary rocks at the beginning of volcanic activity was much the same as the present topography. The contacts of the effusive Packard rhyolite east of Godiva Mountain and of the altered tuff and latitic lavas in the vicinity of Sioux Pass prove that the present limestone surface in this part of the district is practically coincident with the prevolcanic surface. Furthermore, the steep slopes found to exist at these limestone and lava contacts and the considerable thicknesses of the lavas in adjacent prevolcanic valleys show that the prevolcanic valley floors east and south of Sioux Pass were even deeper than the present valleys. Of the 4,300 feet of limestone and dolomite cut by the subsidiary monzonite stock at Sioux Pass, 2,000 feet was above the prevolcanic valley floors. The remaining 2,300 feet at this place and a much less amount over the main monzonite stock can hardly be regarded as sufficient both to furnish material for extensive assimilation by the magma and to act as a batholithic cover over it during the long period of time necessary for differentiation.

On the other hand, when rhyolitic eruptions were followed by latitic eruptions, the great quantity of the latitic material not only filled the deep valleys but probably covered the highest limestone mountains as well (p. 65); furthermore, the heat supplied from the volcanic source had had time to cause a local rise of isogeotherms. Accordingly, there was a distinct approach to batholithic or at least hypabyssal conditions, and the granular though rather fine-grained and porphyritic texture of the monzonite may thus be explained, as may also the fact that it maintained its granular texture to the top of the limestone and perhaps for some distance into the overlying lavas. Most if not all of the limestone formerly in the monzonite areas must have been displaced by the monzonite magma, and the composition of the monzonite can not be attributed to assimilation of this limestone by rhyolite.

It appears from the foregoing discussion that evidence in the Tintic district gives no support to the suggestion made by Daly that monzonites, as well as the more distinctly alkaline rocks, such as syenite and nepheline or leucite rocks, owe their origin to the effects of assimilated limestone upon subalkaline magmas. In the Tintic district the origin of the monzonite and latite must be accounted for in a different way, and simple gravitative differentiation has been suggested as the most probable explanation, although abyssal assimilation of siliceous rocks prior to volcanic eruptions may have had some influence. The syenitic variation of the monzonite, however, is mentioned on page 68 as a possible result of reaction on a small scale between the monzonite and dolomite. Such reaction, which has taken place on a small scale at the uppermost exposed contact of the monzonite, can doubtless take place on a large scale at abyssal depths and be represented in later eruptions; but no later eruptive rocks are exposed in the district other than a few dikes of monzonite porphyry. It may therefore be concluded that although this last bit of evidence suggests the possible derivation of alkaline from subalkaline rocks (including monzonite) through the assimilation of limestone and dolomite, as proposed by Daly, the volcanic period in the Tintic district was not long enough to make this process efficient on a large scale.

EVIDENCE IN THE BASALT.

The relation of the minor occurrences of olivine basalt at House Butte to the other igneous rocks of the district can not be properly considered without a chemical analysis. The rock may belong to a distinctly later volcanic epoch and represent the primary basalt involved in Daly's hypothesis;[1] or it may represent the basic pole of differentiation of the volcanic series of the Tintic district. In the latter case downward migration of the most basic material would eventually develop a basaltic magma beneath the extensive monzonitic magma, and any eruptions in the closing stages of volcanic activity, after the monzonitic magma had consolidated, would necessarily consist of basaltic rock.

CONCLUSIONS AND SUMMARY OF VOLCANIC HISTORY.

The principal conclusions in the foregoing discussion are as follows:

1. The oldest igneous rock in the district is a latite or andesite, but nothing definite is known regarding its ultimate origin—whether it represents a primary or a syntectic magma.

2. The early rhyolite east of the Iron Blossom mine represented by the next eruption may be a differentiate from the latite or andesite, due to gravitative separation of the constituents originally in the andesite; but possible effects of abyssal assimilation can not be denied.

3. The production of the Packard and Swansea rhyolites through the assimilation of siliceous rocks by monzonitic magma some miles below the surface was also possible but quite beyond the realm of proof.

4. The postrhyolite monzonitic rocks represent the magma after the rhyolite fraction in the upper part of the magma chamber had been separated and drained off. They are not due to assimilation of limestone by a rhyolitic magma.

5. There is some indication of the derivation of alkaline rocks on a small scale by marginal reaction between limestone and subalkaline magmas, as suggested by Daly, but the volcanic period was too short to allow the concentration and eruption of any large bodies of such alkaline rocks.

6. The small dikes of olivine basalt may represent either a distinctly later volcanic period or the basic pole of differentiation in the volcanic series of this district.

The order of events, beginning with the earliest known eruption, may be summarized as follows:

1. Earlier latite or andesite eruptions.
2. Long quiescent period; possible silicification of main magma through abyssal assimilation of siliceous rocks; differentiation of the original (syntectic) magma into an upper rhyolitic and lower monzonitic fraction.
3. Eruption of early rhyolite.
4. Eruption of rhyolitic tuff.
5. Eruption of the Packard and Fernow rhyolites and intrusion of the Swansea rhyolite.
6. Explosive eruption of latitic or andesitic tuff, forming the Volcano Ridge cone.
7. Eruption of augite latite from the Volcano Ridge vent, including many of the radiating dikes in the vent.
8. Eruption of the latite-monzonite porphyry of Sunrise Peak, probably including several flows and accompanied by outlying dikes.
9. Eruption of the pyroxene latite flows and dikes, which may be essentially contemporaneous with the monzonite of the Silver City stock.

The coarse agglomerate and tuff and the flows containing basaltic hornblende followed the rhyolite eruption, from unknown conduits or fissures, and may be contemporaneous with a part or all of Nos. 6, 7, 8, and 9.

10. Eruption of olivine basalt, possibly a complementary differentiate to the rhyolite.

STRUCTURE.

The structural features of the Tintic district include folding, faulting, jointing, and features due to igneous intrusion and extrusion. Of these, folding and faulting are mentioned briefly on preceding pages and are thoroughly discussed below. The problem of igneous intrusion is treated in connection with the foregoing descriptions of the igneous rocks, and only the influence of preexisting fissures remains to be considered. As the structural features of the Tintic district are but the local expression of forces active at different periods throughout the Great Basin and even a more extensive area, a thorough consideration of their causes is impossible without a review of studies over this great area. Such a review has not been attempted, and the conclusions

[1] Daly, R. A., The mechanics of igneous intrusion: Am. Jour. Sci., 4th ser., vol. 15, p. 269, 1903; vol. 16, p. 107, 1903.

here expressed are based almost wholly on local evidence.

FOLDS.

Several major and minor folds occur within the Tintic quadrangle. (See p. 21.) All but one are largely concealed by the volcanic rocks, and little can be said of them except that their axes trend mostly north. The only well-defined fold is the large asymmetric syncline that occupies nearly all the area of the Tintic mining district and the territory due east of it. The fold is faulted into differently tilted blocks with corresponding variations of dip. Thus the steep west limb north of Eureka Gulch has an average dip between 60° and 70° E.; south of the gulch the dip is about 80° E. as far southward as the east-west faults near the Herkimer

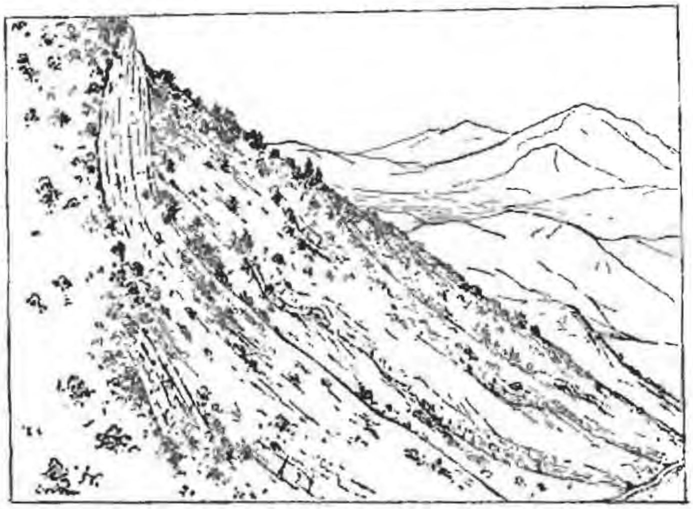


FIGURE 10.—North wall of Pine Canyon, showing changes in dip of limestone beds from 85° W., through vertical to 20° or 25° E. as they approach the synclinal axis.

and Opex shafts; south of these faults the average dip is 80° W. and the syncline is slightly overturned. This reversed dip is shown to continue downward beyond the 2,000-foot level of the Opex, or more than 2,600 feet below the crest of the east-west limestone ridge. There is no indication of an approach to the axis of the fold except in the Emerald and southern Opex workings, where the dip flattens considerably. In the Centennial Eureka and the northern Opex workings the dip flattens locally, but there seems to be no definite character to these places, and they are more reasonably interpreted as local undulations within the west limb of the main fold. Whether they were caused by local variations in the folding stress, by drag along faults, or by the intrusion of the quartz porphyry dikes can not be definitely said; but of the three possibilities the first two seem the more likely. A similar local flattening of dip has been found on the surface from Mammoth Bluffs northward along the southwest summit of Godiva Mountain. (See Pl. V, section B–B′.) The pronounced westward bend in the strike of the quartzite just south of Eureka Gulch also indicates a local undulation, which, as shown on page 77, is closely related to faulting.

The west limb of the main fold includes the whole sedimentary series represented in the district proper and extends from the west base of Quartzite Ridge to the east slopes of Godiva Mountain and Sioux Peak. In Pine Canyon, which separates these two mountains, the bedding is clearly shown to change from vertical, or locally even slightly overturned, to lower and lower dips. (See fig. 10.) At the Utah mine the dip is 20°–25° E.; at the Eureka Hill Railroad the beds lie nearly flat, and farther east they curve gently upward (20°–30°) to form the east limb of the syncline. The east limb is distinctly defined for a mile farther east, but beyond this stretch the beds again flatten and assume a very low northwesterly dip, with local gentle undulations, along axes trending northeast or nearly east. The extensive covering of rhyolite and the complication of faults further obscure the true character of the folding.

The axis of the fold follows closely the eastern edge of the Humbug formation. (See Pls. IV and V.) The axial plane, as shown in the 2,000-foot shaft of the Yankee mine (Pl. V, section A–A′), is nearly vertical. The axis can be traced from the Yankee mine southward to the Iron Blossom No. 3, but beyond these limits it is concealed beneath volcanic rocks. The pitch of the fold is northward, as shown by the curving of the Ordovician strata southeastward toward the axis and by their low northeasterly dips southeast and east of Mammoth. It is also indicated by the different levels at which the top carbonaceous bed of the Gardner dolomite has been found—at the 500-foot level in the Northern Spy, the 900-foot level in the Beck tunnel No. 2, and the 1,300-foot level in the Yankee mine; but east-

west faulting has so greatly displaced the beds north and south of Mammoth that the degree of pitch can not be closely estimated. The synclinal axis extends northward beneath the Packard rhyolite and is again shown at the north boundary of the Tintic quadrangle east of Fremont Canyon. (See Pl. I.)

In the extreme northwestern part of the quadrangle the Ordovician and Mississippian portions of the west limb assume a lower dip and finally, near the head of Broad Canyon, beyond the northwest corner of the quadrangle, cross the axis of an anticline whose west limb has a generally low dip. From these features it is evident that the folding was developed by an eastward thrust that was especially pronounced in the Tintic district as compared with surrounding territory, where both limbs of the folds have gentle dip.

FAULTS.

GENERAL CHARACTER.

Faults of considerable size are abundant throughout the district, although most of them may at first be easily overlooked owing to the similarity between limestone beds of different horizons. The best way to obtain an adequate idea of the faulting is to trace some well-defined bed, such as the Dagmar limestone, from Mammoth Gulch northward. Fissuring, as a rule, accompanied by pronounced faulting, has taken place at different periods; some movements accompanied or closely followed folding; others may have been distinctly later than folding, but older than volcanic activity; others evidently took place during the volcanic period; others followed volcanic activity and preceded ore deposition; and still others, though much less pronounced in the Tintic district, took place after ore deposition. Some faults of different age follow essentially parallel directions, and it is quite possible that more than one movement has occurred along the same fault. Furthermore, no faults have been traced from the quartzite through the shale into limestone. For these reasons it seems best to group the fault descriptions first according to the formations in which they occur and to subdivide them so far as possible according to age, locality, and direction. Only faults in the mining district proper (Pl. IV) are discussed in detail. Those elsewhere in the quadrangle (see Pl. I) are subject to the same interpretations.

FAULTS IN THE QUARTZITE AND SHALE.

FAULTS CLOSELY CONNECTED WITH FOLDING.

Along the quartzite and shale contact are local overthrusts and several nearly vertical easterly faults, all closely related in origin. Besides these at least four systems of joints were seen in the quartzite, following nearly north, east, northeast, and northwest directions. Some are slickensided and some are accompanied by considerable crushing, but the uniform character of the rock conceals the amount of displacement along them. One northeast fissure on the south spur of Quartzite Ridge has been filled by a rhyolite dike. Joints in the shale are not persistent.

The best-defined overthrust is exposed on the south side of Eureka Gulch, where a block of quartzite has been pushed eastward over the shale. Here the strike of the formations swings from nearly north to nearly east (Pl. IV). The shale is not present in the area of easterly strike except in a shallow prospect hole near the east end, where it is overridden by quartzite. It next reaches the natural surface 200 feet farther east, where it is exposed in a narrow band, less than 100 feet wide, which can be followed in a southeasterly to southerly direction for about 500 feet. Here the quartzite and shale contact is offset 250 feet to the west by a vertical easterly fault. South of this fault the shale band is 300 feet thick and shows normal stratigraphic relations to the quartzite. The quartzite north of the fault dips about 60° SW., away from the shale; but south of the fault it dips 80° E., toward the shale. The whole structure is interpreted as follows: The forces active during the period of folding developed a nearly right-angle bend in the quartzite, forcing it against the relatively plastic shale, which presented so weak and uneven a resistance that a block of the quartzite was locally overthrust upon it, producing both the overthrust and the accessory easterly fault at the same time.

The quartzite and shale contact about 630 feet north of Eureka Gulch may be broken by a similar though smaller overthrust and accessory easterly fault, but the evidence here is obscured by fine talus. Over 2,000 feet north of the gulch is a more marked occurrence of the same kind. Here, too, the details are obscured by talus, but the local elimination of the shale and the position of the quartzite boundary in-

dicate beyond a doubt that an overthrust fault is present. There is a similar but greater fault three-fifths of a mile north of the mouth of Jenny Lind Canyon, where the quartzite has moved across the positions of the shale and adjacent limestones for at least 1,800 and possibly as much as 2,400 feet. A thin rhyolite covering here conceals the exact amount of displacement, as well as the arrangement of the shale and limestone immediately south of the fault. That the quartzite has been overthrust is shown by a prospect shaft just south of the fault line and nearly due south of the 7,050-foot summit. The collar of this shaft is in quartzite, but the material on the dump is practically all argillaceous limestone similar to that on the north side of the fault. This fault is the only one found whose contact extends across the shale into the limestone, and it is possible that the total displacement shown represents not only the eastward thrust of the southern block during folding, but a later westward thrust of the northern block caused by the pressure of the rhyolite column in the Packard Peak vent.

All the easterly faults that offset the quartzite and shale contacts are best interpreted as of similar nature to the accessory faults above mentioned. Some are so paired as to indicate a broad quartzitic block thrust farther east than those to the north and south of it; others indicate a steplike arrangement of the blocks. The interpretation implies more or less overthrusting all along the quartzite and shale contact, but the whole contact can not be strictly mapped as a fault, because the movement adjacent to it has evidently been effected by slipping on many surfaces within the shale, which appears to have had its thickness here increased and there diminished by squeezing. The directions of movement along the easterly faults are, according to this interpretation, either horizontal or, more likely, inclined upward to the east. The most conspicuous though not the largest of these easterly faults, which has a strike slip (horizontal offset along the fault plane) of about 250 feet, is just south of the saddle east of Quartzite Ridge and is shown in Plate XVI, *B*.

FAULTS LATER THAN FOLDING.

In the small quartzite area southwest of Robinson, the northeasterly strike and low southeasterly dip form so marked a contrast to the N. 10° E. strike and 80° W. dip of the main mass that there can be no doubt that a strong easterly fault is concealed beneath the alluvium of Mammoth Gulch. The attitudes of the strata on each side of it show that it is distinctly later than the folding, as the gently dipping beds on the south side represent the bottom or trough of the fold, faulted up against the vertical west limb. The vertical displacement can not be measured exactly, but in the quartzite area it must at least exceed 2,000 feet, as north of the gulch there is no indication of the strata curving toward the synclinal axis either on the surface or on the 2,000-foot level (west drift) of the Opex. (See Pl. V, section B–B′.) This fault may mark the north boundary of a block uplifted during the monzonite intrusion, as shown on page 86 and in figure 9; but earlier movements may also have taken place along this same fault plane.

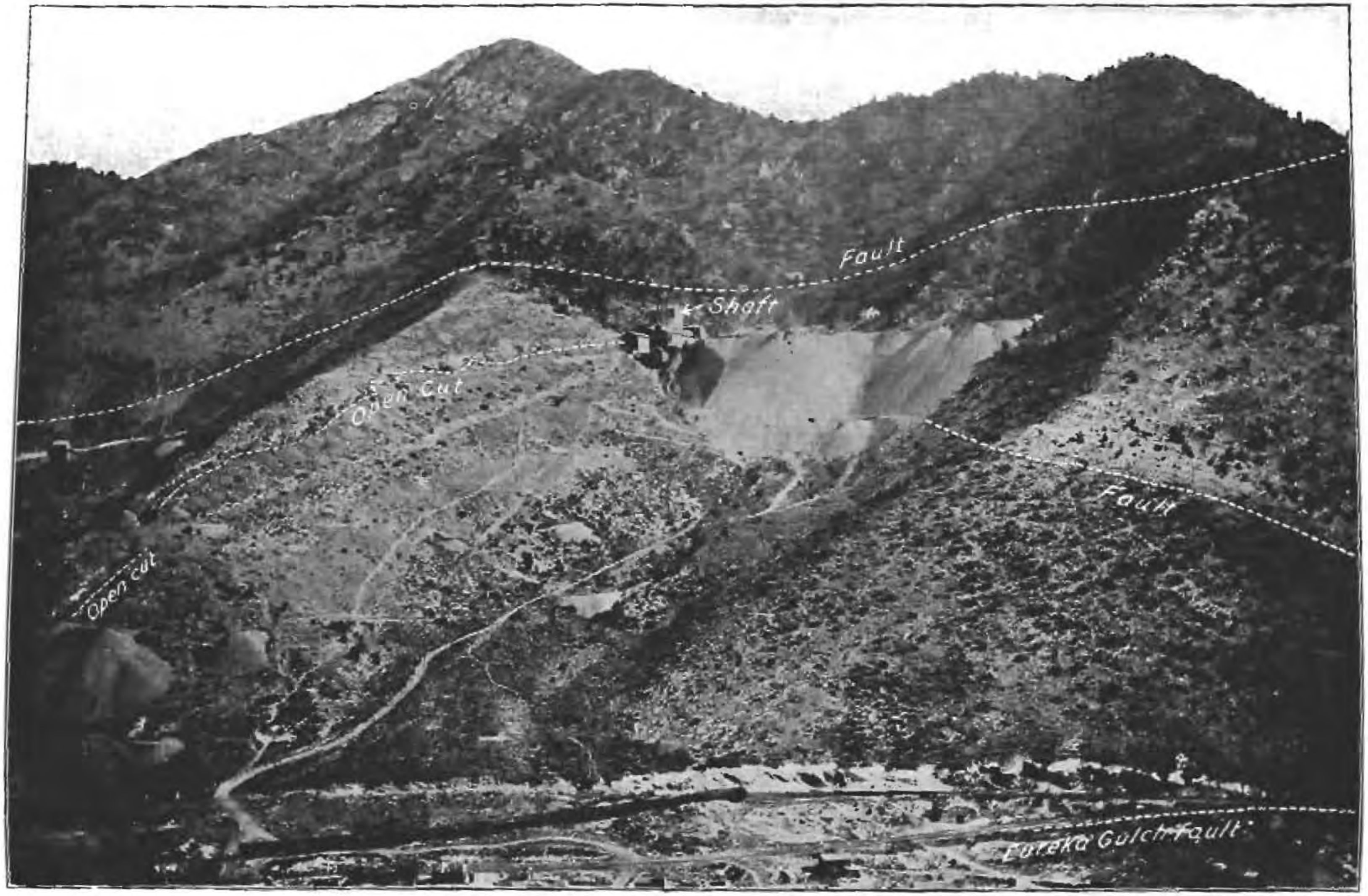
FAULTS IN THE LIMESTONE.

Faulting is abundant throughout the limestone area, especially in its western half (Pl. IV); but the apparent scarcity of faults around Godiva Mountain and Sioux Peak is due to the extensive talus covering and to the more uniform color of the outcropping strata, which tend to conceal them. Fracturing is plentiful in outcrops at both of these places, and several easterly or east-northeasterly fissures have been cut underground, but none have afforded ready data for measuring the amount of displacement.

As regards direction the faults exposed at the surface in the limestone area may be divided into three groups, trending northeast, east, and north-northwest. A fourth direction, near north, is also prominent underground but because of its coincidence with the strike of the strata can not be traced on the surface for any considerable distance. These different groups are as a whole rather sharply defined, as shown in Plate IV, but on close study different groups appear very closely related both as to age and origin, and some faults with parallel strikes appear to differ in these respects; furthermore, certain of the faults have been affected by more than one period of movement. It therefore seems best to group the faults according to relative age and to subdivide them according to location.

A. PHOTOMICROGRAPH OF AEGIRITE-AUGITE PORPHYRY PHASE OF MONZONITE.
O, Orthoclase; P, plagioclase. Magnified 30 diameters.

B. EAST-WEST FAULT SOUTH OF THE SADDLE EAST OF QUARTZITE RIDGE.
a, Top bed of Tintic quartzite; *b*, Ophir formation; *c*, Teutonic limestone (not faulted).



VIEW SHOWING OPEN CUT OF EUREKA HILL MINE AND PRINCIPAL NORTHEAST AND NORTHWEST FAULTS IN VICINITY.

FAULTS CLOSELY CONNECTED WITH FOLDING.

Faults north of Eureka Gulch.—The faults north of Eureka Gulch include one of northeast trend, one of northwest trend, and several of east trend. The geologic structure also shows the existence of a northerly fault beneath the alluvium in Cole Canyon.

These different faults are all closely related and are due to a complication of causes—unequal eastward thrust by the forces that produced the folds and developed major shearing planes, accessory shearing induced by major shearing, and local pinching and bulging of the shale band. The strike shifts[1] (horizontal components of movement parallel to the fault line) are pronounced along all these faults except the northerly one. Upward movement to the east is also pronounced along the few faults where slickensided surfaces are exposed. That some rotation of blocks also took place during the faulting is shown by discordances in dip on opposite sides of fault planes, but these differences are as a rule not sufficient to account for more than a minor fraction of the total displacement, or even the strike shift.

An important feature of this interpretation is that although some of the faults—for instance, the northwest fault near the Dagmar—are "normal" in attitude, they were not necessarily induced by tension. Tensional stresses, complementary to the principal compressive stresses, were doubtless operative in a north-south direction and may account in part for the open character of many of the easterly fissures, as may also later movements, considered below (pp. 82–86).

The northernmost fault shown in Plate IV is most clearly exposed on the ridge just southwest of the Paxman shaft and can be followed easily across the saddle in the next ridge to the southwest, beyond which it disappears beneath talus and alluvium. Farther southwest, on Bluebird Spur, west of Cole Canyon, its trend is again shown by the northeastward offset of the Dagmar limestone. Beyond this point it is concealed beneath talus, but it does not extend across tho shale, as the quartzite in line with the fault is displaced eastward by a local overthrust. The dip of the fault plane, as shown by its course over an undulating surface, is steep to the southeast. There is no strike shift at the limestone and state contact, but the shift is between 225 and 250 feet at the outcrop of the Dagmar limestone and nearly 600 feet near the Paxman shaft. The movement may have been in part of a rotary nature, the axis lying in the shale belt and the amount of displacement increasing eastward; but the increasing eastward displacement is for the most part the result of contemporaneous movement along the northwest fault, whose strike shift is 450 to 500 feet.

The prevailing eastward thrust exerted during the period of folding was, as is shown by the map, especially pronounced in the vicinity of Jenny Lind Canyon, where it produced a bulge and small easterly faults in the quartzite and thrust the immense limestone block, bounded on the south by the west-northwest and northeast faults, upward to the northeast.

The northeast direction of movement of the triangular block between these two faults and the Ophir formation was induced largely by the movement of the block just described—removal of support along the northwest fault caused yielding to the general eastward thrust. The yielding of shale in the Ophir formation was complementary to the movement of these two blocks. Where the eastward thrust was greatest the shale was squeezed, but it bulged to the south, taking up the space made available by the movement of the triangular block.

The easterly faults near the Dagmar shaft in the triangular block are attributed to accessory movements induced by shearing stresses that were active along the main oblique faults.

The area south of the triangular block was also one of pronounced compression, as shown by the thinning of the shale and by local overthrusts along the quartzite and shale contact. The easterly faults in the limestone of this area are attributed to this local compression. It is noteworthy that none of these faults, although their strike shifts are considerable, extend eastward across Keystone Ridge. Movement along them was evidently taken up along the northerly fault beneath Cole Canyon.

Faults between Eureka Gulch and Eureka Peak.—The greatest and most complicated fault zone lies along Eureka Gulch and on the slopes west and northwest of Eureka Peak. (See Pl. XVII.) The faults along Eureka

[1] Name proposed in Reid, H. F., and others, Report of the committee on the nomenclature of faults: Geol. Soc. America Bull., vol. 24, p. 172, 1913.

Gulch are largely concealed beneath alluvium, and only an incomplete indication of them is given by the isolated outcrops of the Ajax and Opohonga limestones; but the general strike shift is about 2,000 feet. One fault contact is exposed at the westernmost switch on the Denver & Rio Grande Railroad, where the cherty Ajax limestone with northerly strike and vertical dip is in contact with the Cole Canyon and Opex dolomites, which strike north-northeast and dip 60°-80° S., and which are beveled off along the fault. The fault plane strikes northeast, about parallel to the northern track, and dips southeast.

On the southeast side of the fault exposure the rocks are highly brecciated and cut by short faults in various directions, but the general strike of the beds swings from northeast through east and finally around to south, which is the normal strike between Eureka and Mammoth gulches. The corresponding changes in dip are from southeast to south and finally to 80° E. These changes show that the beds on the south side of the fault suffered both a reversal of dip and a bending of strike such as would result from a powerful thrust, either horizontal or upward to the northeast. On the west the brecciation continues as far as the Golden Ray tunnel, directly opposite the local quartzite overthrust described on page 77. On the east the brecciated area passes into three recognizable faults—two of northeastward trend, which are parallel to or slightly diverging from that exposed on the railroad, and one of S. 60° E. trend, which extends toward the Centennial Eureka shaft and whose outcrop indicates a pronounced southwest dip. Along the latter fault the direction of movement may be realized by the relative southeastward offset of its southwest wall and by the partial elimination of the Opex dolomite in the wedge at its southeast end, data which indicate an upward easterly movement of the southwest with respect to the northeast wall. The fault thus appears to be a reverse fault.

Before an explanation of these faults is offered, attention should be called to the strong northeasterly fault which extends northeastward from the shale belt near the Herkimer shaft, passes close by the Centennial Eureka shaft, and disappears beneath the alluvium north of the Eagle and Blue Bell shaft. It is accompanied by brecciation northeast of the Herkimer and by local abnormal strikes and dips southwest of the Centennial Eureka shaft. The strike shift, expressed by a relative northeast movement of the southeast wall, is very little near the shale but increases within the next 800 feet to 250 feet, an amount which continues as far as the Centennial Eureka shaft or to the concealed junction of this fault with the S. 60° E. fault. Beyond this junction the displacement is much greater, but its amount is complicated by large displacements along four other faults whose strikes range from S. 70° E. to S. 80° E.

The origin of most if not all of these faults is believed to be similar to that of the faults north of Eureka Gulch, although the present displacements along some of them are evidently the result of more than one movement. The forces that developed the great easterly flexure in the quartzite and adjacent limestones and produced the local overthrust in the quartzite were effective throughout the exposed limestone section. The flexure passed northeastward into the Eureka Gulch fault, and the flexed limestones on the south were shoved past the unflexed beds on the north. Just as the flexure in the quartzite may be regarded as an unsymmetrical anticline with its axis nearly normal to the surface, so the Eureka Gulch fault may be regarded as a related overthrust with its plane in a corresponding normal position. The drag or shear along the south block was so great that the block itself was dislocated by the two additional northeast faults and by the S. 60° E. fault. The fault last mentioned may be regarded as an oblique branch overthrust within the main overthrust block.

The origin of the northeast fault that passes south of the Centennial Eureka shaft and of the associated S. 70°-80° E. faults south of the Eagle and Blue Bell shaft is more difficult to explain. As the southwest end of the northeast fault is near an eastward bulge in the quartzite contact, the fault and the bulge may be related, and the northeastward increase in displacement may be attributed to a small amount of rotation. From the Centennial Eureka shaft eastward, however, the cause of the directions and amounts of movement is complex. The block that lies due east of the Centennial Eureka shaft and is bounded on the north by a S. 80° E. fault has moved eastward

and upward with respect to all the neighboring blocks. Were this block restored to alignment with the adjacent block to the north, the displacement along the northeast fault would show only a normal northeastward increase, such as could be attributed to rotation. It is furthermore noteworthy that this eastward upthrust block would then be in line with the wedge-shaped block that moved in approximately the same direction west of the Centennial Eureka shaft, and it thus appears that the S. 80° E. fault on the east of the northeast fault is a faulted continuation of the S. 60° E. fault on the west. This correlation implies that the S. 60°-80° E. fault was formed prior to the northeast fault.

The interval between the two movements was not necessarily great and may have been wholly within the period of folding, but it is also possible that a part or all of the movement along the northeast fault may have taken place later, during the volcanic period, as is true of the Emerald-Grand Central fault described under the next heading. It is also probable that concealed northerly faults, formed during or after the period of folding, have been of some influence in determining the final positions of the fault blocks south of the Eagle and Blue Bell shaft. The details of faulting are too complicated to be fully accounted for, but it is obvious that the forces acting during the period of folding were also complicated and capable of producing faults in various directions. The conclusion is therefore warranted that most of the faulting between Eureka Gulch and Eureka Peak was due to stresses acting during the period of folding, though after the shapes of the major and the minor folds had been determined; but that there is some doubt as to the exact origin of the faults south of the Eagle and Blue Bell shaft. These seem in part due to stresses acting in the period of folding and possibly in part to forces acting in later periods.

Faults between Eureka Peak and Mammoth Gulch.—Faulting is much less complicated south of Eureka Peak, but for the most part it can not be definitely correlated with any one period of disturbance. Most of the faults mapped are small and of easterly trend. Those north of the Herkimer shaft appear to be accessory to the northeast fault that passes just south of the Centennial Eureka. The most prominent of these, which extends eastward to the Opex shaft, owes its irregular surface course to its dip of 50°-60° S. and to the undulating character of the surface. Movement along it has been marked by some rotation, as the beds to the south dip 80° W. and those to the north dip 80° E. It is interrupted by a later northerly fault.

The many easterly faults exposed south of the Herkimer shaft along the Dagmar limestone may be considered steplike offsets corresponding to the eastward bulge of the quartzite and shale west of them. Those along the Cole Canyon and Emerald dolomites may also be due in part to similar thrust, but their offsets are not continuous and in places are opposed to one another, as if their movements were more closely related to concealed northerly faults formed after the folding period. (See figs. 11 and 12.)

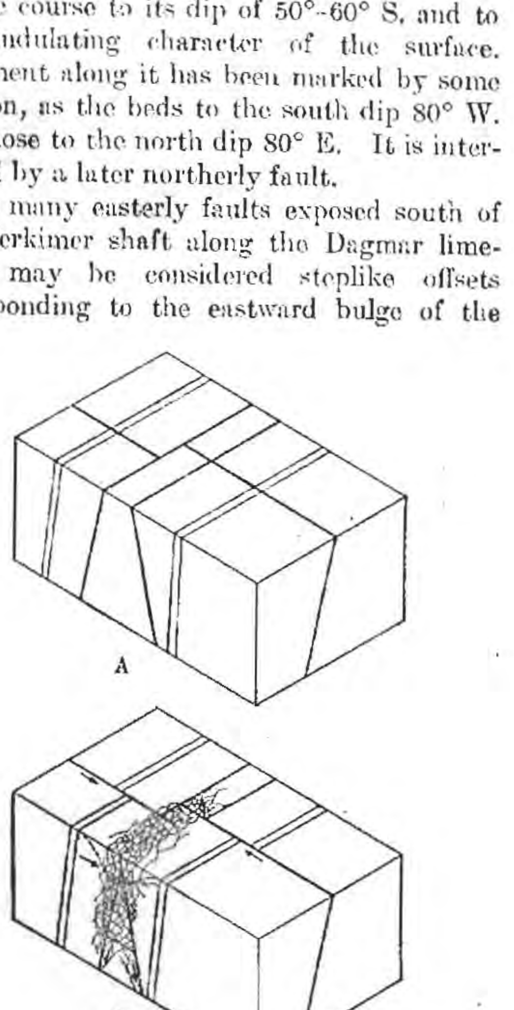


FIGURE 11.—Block diagrams illustrating faults caused by settling of a block with an upper wedge end. A, Before faulting; B, after faulting.

The Emerald-Grand Central fault, which passes northeastward by the Emerald and Grand Central shafts, is essentially parallel to the more prominent northeast faults above described and attributed to stresses active during the period of folding; but any similar

relations which it may have shown to deformation of the quartzite have been obliterated by igneous intrusion and erosion. This fault, however, has displaced a rhyolite dike in the Opex mine (fig. 13), and, although it may have originated during the period of folding, the most pronounced movement along it was distinctly later, during the monzonite intrusion. It is considered further on page 84 with other faults formed at that time.

The northeast faults around Mammoth are not sufficiently exposed to suggest any reliable clue as to their origin. Only their horizontal offsets are known. Their arrangement resembles that east of the Centennial Eureka shaft, and they may therefore possibly have been initiated during the period of folding; but they do not bear the same significant relations to folds, and it is more probable that the greatest movements along them took place later. The faults in Godiva Mountain and the probable fault along Pine Canyon are also of uncertain age and origin.

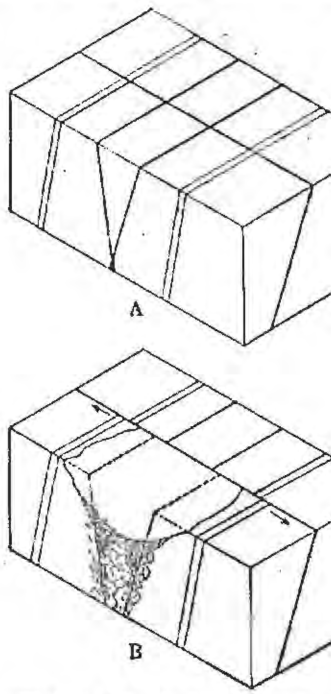


FIGURE 12.—Block diagrams illustrating faults caused by settling of a block with a lower wedge end. A, Before faulting; B, after faulting.

It may be remarked, finally, that the faults most clearly associated with the stresses that produced the folding bear no relation to the topography, and this lack of relation would be expected of compression faults, whose shattered zones would largely be recemented by the compression and recrystallization. The Eureka Gulch fault may appear to give evidence contradictory to this statement, but the trend of the gulch does not parallel the lines of principal displacement, nor do the ore bodies spread laterally along them. Open fractures also are abundant beneath the gulch and may account for its location, but either they are minor tension fractures formed as a result of the compression fault, or else they belong to one of the fracture systems of later origin.

FAULTS DISTINCTLY LATER THAN FOLDING BUT ANTEDATING VOLCANIC ACTIVITY.

Faults formed distinctly later than the period of folding can not be so definitely correlated with any particular stage of deformation, partly because later movements may have taken place along faults already existing and partly because the new fissure systems formed by forces active at different times since the folding period tend to parallel one another as well as some of the older faults. For these reasons it seems best to outline the causes of deformation later than the folding, and to show their generally similar influence in the shaping of the directions of faults, without attempting to distinguish sharply among them.

At the end of the period of folding the rocks that had suffered an east-west compression and a corresponding north-south tension would undergo a recoil movement, owing to their elastic properties, contracting in a north-south direction and expanding in an east-west direction. A further inducement to the same readjustment would be contraction due to loss of heat generated by friction during folding; but changes from loss of heat would, owing to the poor conductivity of rocks, be slower than changes effected by elasticity. The elastic properties of rocks, however, are known to be insufficient to bring about a complete recovery from the effects of compression and heat, with the result that readjustment must be largely brought about by fissuring. The fissures would, therefore, develop on lines normal to the directions of readjustment—that is, parallel to and at right angles to the strike of the strata. As fissures formed during the period of folding already existed in both of these directions, the readjustment could have taken place to some extent along these

old fissures and it may have caused the formation of new fissures parallel to the old ones. The fissures formed or influenced by this readjustment would tend to be open rather than tight.

Another influencing factor would be the isostatic readjustment of the rocks in the zone of quasi-flowage beneath the outer zone of intense folding, as postulated by Chamberlin.[1] According to this hypothesis, the increase of overburden in upfolded areas of the outer zone would set up in the inner zone a movement analogous to glacial creep away from the upfolded areas. There would be a resulting collapse and settling of the outer zone—in other words, tensional or normal faulting—which could last over a considerable period of time. The faulting would naturally take place along the fissures already formed, especially easterly and northerly faults bounding relatively small blocks; the open character of the fissures would be largely maintained; and the principal movement along the fault planes would be downward, in contrast to the oblique upward and eastward movement along faults formed during the period of folding.

These three forces, all of which were active at the end of the period of folding, tended to produce the same result, which is best expressed by the discordant relations of easterly faults on the spurs southwest of Eureka Peak. The displacement on one spur may be just the reverse of one directly opposite on the next spur. The only apparent explanation of such opposite displacements is that an intervening wedge-shaped block (with its thin edge uppermost) must have settled along northerly fissures and that the adjacent blocks, thus left with unsupported sides, settled toward each other (fig. 11, A and B, p. 81) by slipping along easterly fissures; or that a wedge-shaped block with its thin edge down settled and thus separated the blocks on both sides of it (fig. 12, A and B). These northerly faults, which lie along shallow gulches, are concealed on the surface by débris, but their positions are indicated where easterly faults on opposite sides of the gulches are displaced in opposite directions. The gulches owe their origin to the rapid erosion of shattered rock along the fault.

Although block faulting of this type can be proved only where easterly faults are sufficiently numerous, there is no reason to believe that it is not present throughout the district. The most conspicuous of the block faults are near the Opex shaft and south of the Eagle and Blue Bell shaft.

The larger easterly faults that have not been assigned to the period of folding may be in part due to these settling movements, but the amount of displacement along them is so great in comparison to that along the faults just described that it seems probable that the principal movement along them was due to later disturbances which accompanied volcanic eruptions. The most conspicuous of these faults is that extending from Mammoth eastward to the Northern Spy mine. Another one, which is rather obscure, extends along the upper part of Jenny Lind Canyon.

FAULTS FORMED DURING VOLCANIC ACTIVITY.

The concealment of the sedimentary beds beneath volcanic rocks around all the vents in the district except along the northeast boundary of the monzonite prevents thorough study of the influence of preexisting faults on volcanic eruption; but the network of faults and the readjustment that followed the period of folding must have made conditions favorable for eruption. If the fissuring extended deep enough to reach the magma chamber, the more open fissures would admit dike intrusions; upward-converging fissures would permit the settling of intervening blocks, which would be displaced by ascending lava. Block after block could thus be displaced. Furthermore, the forces that were sufficient to push the lavas upward from unknown depths to the surface must also have exerted considerable upward pressure upon the fissured rocks above and immediately adjacent to the upward-moving lava columns, especially as the ascending lava approached the surface. Thus, where a block was so situated that the magma could not work its way upward around it, the upward force could have pushed it upward or outward until a conduit to the surface had been opened. The conduits must have been formed either by such an upward and radiating thrust, or by a collapse and engulfment of the rocks which the conduits now replace, or, as field evidence in the monzonite area suggests, by a combination of the two processes. So far as positive structural evidence indicates, the thrusting process was the more effective.

[1] Chamberlin, T. C., The fault problem: Econ. Geology, vol. 2, pp. 7?4-724, 1907.

The evidence of faulting connected with the beginning of volcanic activity is to be found in part along faults that are discovered in preceding pages. The most convincing evidence is that afforded by the "parting," or main fault in the Opex mine. This fault has been found to extend northward into the Centennial Eureka mine, where it bounds the main ore bodies on the east and is known as the "east limit" fissure. The trend of the fault in the lower Opex workings is nearly north, but it curves northward and upward to an undulating north-northeast course as far as the 1,300-foot level of the Opex and the 1,200-foot level of the Centennial Eureka. Its continuity in the Centennial Eureka is interrupted by one or more cross breaks of southward dip. The principal interruption is noted at the cross break on the 1,200-foot level about 1,800 feet south-southeast of the Centennial Eureka shaft. South of this point the fault strikes east of north and dips westward; north of it the fault lies about 150 feet farther west and has a northerly strike and a vertical dip, corresponding with the bedding between the 1,000 and 500 foot levels. About 1,300 feet southeast of the Centennial Eureka shaft, it may be again deflected westward and its northward continuation marked by the Rhode Island stope.

The trace of this fault is not apparent on the surface, because of coincidence with the vertical bedding, and is only roughly indicated on the map. Its northern part is shown about 900 feet east of the Centennial Eureka shaft, where its approximate position is indicated by the discordance in the amount of offset along the cross faults on each side of it. Farther south there is nothing to indicate the fault along the surface.

In the lower Opex workings a rhyolite dike has been offset by this fault (the "parting"), as shown in figure 13. Here the east wall of the fault has moved northward for 350 to 400 feet horizontally and for 200 feet upward. The faulting thus took place after the intrusion of the rhyolite, and the movement of the east wall was away from the monzonite, whose northern contact is not correspondingly faulted. As the only known disturbance that occurred during this time was the monzonite intrusion, it is concluded that the fault was due to the thrust of the monzonite magma.

The interruptions of the fault along the southward-dipping cross break indicate that the northward, upward movement shown along the "parting" took place also along the south wall of the cross break or was distributed along two or more parallel cross breaks. According to this interpretation the parts of the cross breaks east of the fault are compression faults, whereas the parts west of the fault have not been compressed but may even have been opened to some extent. This conclusion may have some bearing on the fact that the large ore bodies in the Centennial Eureka lie along these cross breaks west of the northerly "east limit" fault but do not continue to the east of it. The underground evidence, however, is too meager for this statement to be regarded as more than a suggestion.

The Emerald-Grand Central fault is marked by a displacement similar to that along the "parting" or "east limit," just described, the east wall moving relatively northward. Its dip in the Emerald mine is 50°–70° W., and if continuous in this direction should bring it very close to, if not into junction with the southernmost exposure of the "parting" on the 2,147-foot level of the Opex. The dip in the Grand Central, so far as shown by the few exposures, is about the same as in the Emerald. The position of this fault with respect to the monzonite mass, the direction of displacement, and its close relation with the "parting" all tend to indicate that the faulting was caused by the pressure of the monzonite magma.

On Plate IV is shown a distinct southward divergence of the sedimentary formations just north of Mammoth, all those west of the Opohonga limestone curving westward and those to the east curving eastward. The axis of divergence is approximately on a line with the northward-projecting prong of monzonite at the Lower Mammoth mine. The structure suggests that the pressure of the intruding monzonite was sufficient to pry the sedimentary rocks apart. If this was so, the easterly faults just north of Robinson may represent, wholly or in part, dislocations caused by the westward thrust, rather than those formed as the result of folding. This movement evidently preceded that along the Emerald-Grand Central fault, though both were closely related.

The intrusion of the Swansea rhyolite may also have exerted a prying effect, and it is noteworthy that no inclusions of quartzite or limestone have been found in it, but its position and contacts have been so changed by faulting caused by the monzonite intrusion (p. 86) that its influence on the structure of the sedimentary rocks is practically obliterated.

The great Mammoth-Northern Spy fault zone is believed to be due, at least in part, to the opposite sides of the fault are about equal. Here the upper beds of the Bluebell dolomite on the south are opposite the upper beds of the Pine Canyon limestone, indicating a vertical displacement of at least 1,000 and perhaps as much as 1,500 feet. Some of this movement, as already suggested, may have taken place during the period of settling previous to any volcanic eruptions, but the great amount of vertical uplift on the same side of the fault as the monzo-

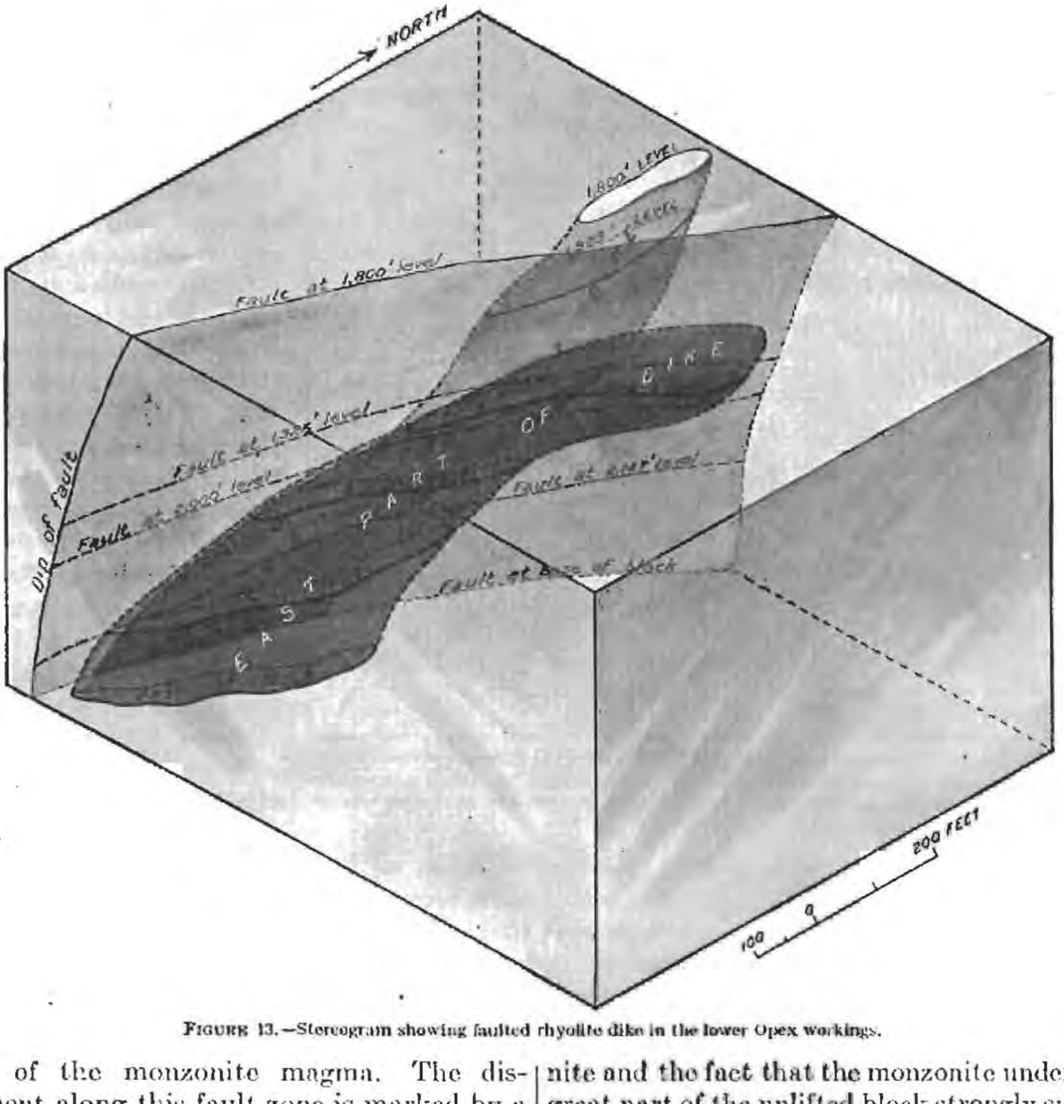


FIGURE 13.—Stereogram showing faulted rhyolite dike in the lower Opex workings.

thrust of the monzonite magma. The displacement along this fault zone is marked by a relative rise of the south wall, sufficient to bring the nearly flat beds in the trough of the syncline up to the level of the nearly vertical beds of the west limb. (See Pl. V.) The apparent great horizontal offset along this fault is due chiefly to these differences in dip. The actual vertical displacement is best expressed along the slope near the Northern Spy shaft, where the dips on nite and the fact that the monzonite underlies a great part of the uplifted block strongly suggest that the fault was due to the thrust of the rising monzonite magma. The numerous limestone inclusions in the monzonite along the southwest edge of this block show that after the block had been raised it underwent partial replacement, through stoping, by the still fluid monzonite. Some of the large inclusions near the contact may be eroded roof pendants, but others, espe-

cially those found underground and not on the surface, have been completely detached by the magma.

The discordant relations between the Packard rhyolite and the latite-andesite series east of the Northern Spy shaft may be due to this fault or to closely associated faults, but their contacts are too completely hidden by débris to permit any more positive statement.

The northeast faults around Mammoth may have been due, wholly or in part, to the monzonite intrusion, but convincing evidence is lacking.

Another block that appears to have been first upfaulted and then largely destroyed by the monzonite magma includes the main body of Swansea rhyolite and the associated quartzite in the lower part of Mammoth Gulch. The suggested lines of faulting are one nearly due east, connecting the north end of the main rhyolite mass with the south end of the small body southeast of Robinson, as indicated in Plate IV; also a northerly line in the present monzonite area, passing between the quartzite inclusions on the west and the limestone inclusions on the east. The easternmost quartzite inclusions are rather sharply separated from those of limestone along this northerly line. Furthermore, the tunnel entering the monzonite south of Robinson (Pl. IV) extends for most of its length through large blocks of metamorphic limestone which lie just east of large quartzite inclusions, but 200 feet lower. It may be argued that the quartzite, being lighter than the monzonite, was floated upward in the lava, while the heavier limestone blocks sank; but it is impossible to explain the marked separation of the quartzite and limestone in this way, for blocks of the quartzite, which everywhere underlay the limestone, should have also been floated up among the exposed limestone blocks, and other limestone blocks should have settled among the exposed quartzite blocks. If it is contended that the limestone blocks were too large and too numerous to allow underlying quartzite blocks to rise among them, it must also be explained why the limestone blocks west of a certain line all sank below the present surface and below the quartzite inclusions, leaving no trace of their existence, while the blocks east of that line have sunk little, if any. The difficulty is lessened by assuming that the line between the limestone and quartzite inclusions was a fault with upward and westward displacement on its west side, as shown in figure 14. The upward displacement along this fault can be roughly estimated by comparing the position of the quartzite inclusions with a restored section of the sedimentary rocks, as in Plate V, section C–C'. It must have been, according to this section, at least 1,200 feet. According to figure 14, in which more factors are considered, it may have been as much as 4,000 feet. The westward component of displacement is indicated in Plate V by the distance between the west boundaries of the main mass of Swansea rhyolite and the small body southeast of Robinson. The fact that the faulting was later than the rhyolite but was largely obliterated by the monzonite indicates that it was contemporaneous with the rising of the monzonite magma. The present inclusions of quartzite may be in part roof pendants, or blocks stoped from the bottom of the uplifted block.

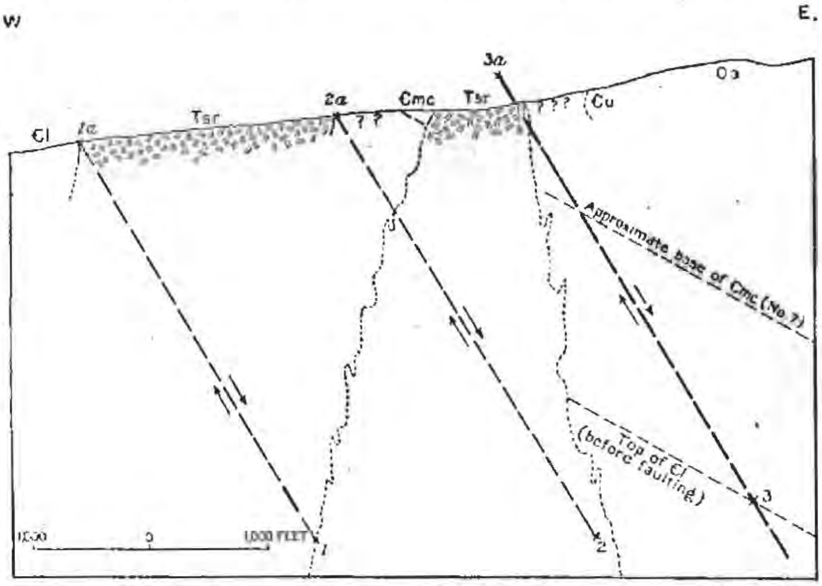


FIGURE 14.—Generalized section showing suggested faulting after the intrusion of the Swansea rhyolite and just before the intrusion of the monzonite. 1 and 1a, 2 and 2a, 3 and 3a represent approximate positions of certain points before and after faulting. For explanation of other symbols see Plate IV

Another fault that was formed and later almost completely obliterated by the monzonite intrusion is suggested by the quartzite inclusions just north of the Martha Washington shaft and those southwest of the Sunbeam shaft. The inclusion near the Martha Washington shaft should, if the sedimentary rocks were restored, lie at least 2,000 feet below the present surface, and its position close to the eastern edge of the clearly intrusive monzonite does not favor the view that it was floated upward that amount. The absence of limestone inclusions west or southwest of this place is also striking, and the combined evidence suggests that an easterly fault may have been formed by the intruding monzonite a short distance north of the Martha Washington shaft and the block south of it thrust upward. If this was so, the uplifted block was later displaced or stoped away by the monzonite, and all that remains of it to-day is the small number of inclusions, mostly of quartzite but one of Swansea rhyolite.

The only evidence of possible displacement accompanying rhyolite eruptions consists of the easterly faults in and northwest of the upper part of Jenny Lind Canyon. The north walls of these faults have been relatively moved upward to the west, and their positions with respect to Packard Peak suggest that blocks may have been thrust upward and outward from the rhyolite vent. The evidence is so obscure, however, that nothing more than this mere suggestion is warranted. The width of the Swansea rhyolite and the absence of inclusions within it suggest that some faulting may have been caused by its intrusion, but all data on the problem are concealed by alluvium or have been destroyed by the effects of the monzonite intrusion.

METHOD OF MONZONITE INTRUSION.

The foregoing descriptions give some indication of the method of the monzonite intrusion after the magma had risen within a few thousand feet of the present surface, or to a point where the strength of the overlying formations was insufficient to withstand the upward pressure of the magma. As shown by the map (Pl. IV), there was evidently some prying apart of the older rocks, either by the Swansea rhyolite or by the monzonite, but the opening for the monzonite magma was made principally by faulting. Large blocks of the premonzonite rocks were pushed upward and outward from the central part of the present monzonite area, and openings may well have been formed through which the magma reached the surface and added surface flows to the great latite-andesite series. After pressure against the rising magma had been relieved in this way the magma continued to enlarge its chamber upward by displacing or stoping blocks of limestone, quartzite, and, probably in small part, Swansea rhyolite. The stoping process, as shown in Plate V, was of considerable extent but does not seem to have had as great an effect as the faulting which preceded it.

It is taken for granted in the preceding discussion and in the discussion of differentiation that the quartzite and limestone inclusions in the monzonite sank in the magma, or at least did not rise to any appreciable extent. As there is much skepticism regarding the possibility of a rock as light as quartzite sinking in a magma as heavy as that of monzonite, a short discussion of the question is pertinent. So far as field evidence is concerned, the principal difficulty with the assumption that the quartzite blocks rose from great depths is their marked localization with respect to those of limestone, as shown on page 86 and on Plate IV. The interpretation just given of faulting upward and outward from the center of intrusion and the subsequent stoping of fragments from the fault blocks avoids this difficulty.

The question of relative specific gravity of sedimentary and igneous rocks has been considered by Daly,[1] who quotes figures based on experiments by Douglas, Delesse, and Barus, showing the specific gravity of different igneous rocks and of their corresponding glasses or melts at different temperatures. Daly also shows the actual and calculated specific gravities of sedimentary rocks at corresponding temperatures. The specific gravity of the monzonite, Tintic quartzite, Herkimer limestone, and Bluebird dolomite, determined by George Steiger, is given in the first column of the table on page 88. The figures in the other three columns, estimated by comparison with corresponding figures quoted by Daly, indicate the specific gravity at high temperatures at which the monzonite was still fluid.

[1] Daly, R. A., The mechanics of igneous intrusion, third paper: Am. Jour. Sci., 4th ser., vol. 26, pp. 27-28, 1908.

Specific gravity of monzonite and sedimentary rocks at room temperature and high temperatures.

	Room temperature.	1,000° C.	1,100° C.	1,200° and 1,300° C.
Hornblende-biotite monzonite (probably affected by pneumatolytic action)	2.659	2.38	2.37	2.36
Augite monzonite (unaltered)	2.729	2.45	2.44	2.43
Tintic quartzite	2.638	2.56+	(a)	2.56
Herkimer limestone	2.695	2.61+	(a)	2.61
Bluebird dolomite	2.832	2.74+	(a)	2.74

[a] Comparative data for this column are not given in Daly's table.

According to these figures, only the dolomite is heavier than the unaltered monzonite at room temperature, but all the sedimentary rocks, including the light quartzite, are distinctly heavier than the monzonite at high temperatures. The accuracy of these figures may of course be open to question, because of the difficulty in preventing the escape of occluded gases in the rocks at high temperature. Inaccuracy due to that cause, however, would tend to render the figures for all the rocks too high, rather than too low. Furthermore, the amount of contact metamorphism and pneumatolytic action associated with the monzonite, though not unusually great, is sufficient to show that considerable volatile matter was present in the monzonite magma and this would also render the actual specific gravity of the magma less than the calculated gravity given in the table. The experimental data therefore agree, so far as they go, with the facts observed in the field and favor the conclusion that the quartzite as well as the limestone inclusions may have sunk in the magma or at least did not rise to any appreciable extent.

FAULTS OR FISSURES FORMED SHORTLY AFTER VOLCANIC ACTIVITY.

The general trend of fissures in the monzonite is north-northeast to northeast, paralleling the long axis of the monzonite mass. The chief mineralized fissure in the Swansea rhyolite trends north to N. 15° W., but this too parallels the contact between monzonite and rhyolite. The main fissures are in places linked directly together, and a few of them are connected by cross fissures of northwest or northeast trends. The two principal fissure zones along the east boundary of the exposed monzonite have an average trend of N. 20° E. and continue in the metamorphic limestone as far as the great easterly fault at the Northern Spy. Here they connect with the two northerly mineralized fissures that lie in and a little west of the synclinal axis.

The arrangement of the fissures in and near the Silver City stock of monzonite is such as might be expected to result from contraction during the cooling of the monzonite. Under such conditions fissures would develop generally parallel to and normal to the cooling surfaces, both within the cooling mass and in the surrounding rocks. Oblique fissures also might be formed, especially in the central portion of the cooling mass, toward which successive zones of contraction would become more and more circular in outline. Several systems of fracturing might result, all formed at approximately the same time. Curved fissures might result where the cooling surface was curved, or where one fissure in forming approached another formed at the same time or even somewhat earlier. The direct linking together of nearly parallel fissures and the dying out of two nearly parallel fissures on opposite sides of a connecting cross fissure are also results to be expected from such contraction. It is true that some or all of these relations may be effected by other forces, such as expansion on relief of compression and folding; but in the Tintic district folding (compression) and subsequent expansion stresses clearly preceded the eruption of the igneous rocks. The only forces active since the monzonite intrusion have been contraction due to cooling and the stresses that produced the Basin Ranges. The faults that border these ranges, however, are marked by valleys, are as a whole distinctly later than the volcanic eruptive period, and in some districts of Utah at least appear to be distinctly later than the period of ore deposition; whereas the fissures in and around the monzonite are mineralized and are quite independent of the topography.

The contraction of the monzonite into a number of detached blocks or slabs parallel to the long axis of the area would necessitate subsequent settling accompanied by more or less faulting, but no faulting of very great

displacement. If the isostatic readjustment (p. 83) that followed folding was still in progress, after the consolidation of the monzonite, it could serve to increase any faulting in the monzonite and perhaps could be suggested as a strong factor in determining the directions of the main fissures. Such settling would tend to close certain of the fissures and to open others, and the latter would become the channels along which ore-forming solutions could ascend.

The same contraction would affect the metamorphic limestone and might extend some distance beyond the metamorphic zone in the overlying limestone. Additional settling and fissuring, to compensate for the vast quantities of rhyolite and latite transferred from the magma chamber to the surface, would take place in the quartzite-limestone area. Many of the postvolcanic fissures, including probably those along the synclinal axis, would doubtless coincide with older fissures, but some of them appear independent, as may be the case with the mineralized fissures in the Mammoth-Grand Central ore zone, which, although closely connected with the Emerald-Grand Central fault zone, trend as a whole across it.

The postvolcanic mineralized fissures in the limestone very commonly curve from their regular courses where they approach older cross fissures, and their continuations beyond the cross fissures are not in line and may follow different trends. This feature, which has produced deflections in the trends of several ore bodies, is noted in several of the mine descriptions. It is rather common for a single fissure on one side of a cross break to be followed by two parallel fissures on the opposite side, and at such junctions with cross breaks the best ore shoots are likely to be found. The formation of the postvolcanic fissures was accompanied by considerable shattering, especially at and near their junctions with cross breaks; but as they are mostly parallel or nearly parallel to steeply dipping or vertical strata the amount of displacement along them is nowhere known to be very great.

Several dikes of monzonite porphyry in the Iron Blossom No. 1 mine appear to be faulted, and the contacts between the limestone and the main porphyry mass on levels No. 2 and No. 7 of this mine show some indications of faulting. A monzonite porphyry dike on the 480-foot level of the Iron Blossom No. 3 also appears to be faulted. It is not known whether these possible faults antedate or postdate mineralization.

The postvolcanic fissuring lasted over a considerable period, as might be expected in a slowly cooling volcanic region. Along some fissures that had been or were being mineralized there was renewed movement, causing a shattering and subsequent recementing of the ore.

FAULTS DISTINCTLY LATER THAN MINERALIZATION.

It is very probable that the postvolcanic fissuring continued intermittently after mineralization and overlapped the Basin Range faulting, which is still going on in some parts of Utah. The age relation of Basin Range faulting to ore deposition is not clear, especially in the Tintic district, where there is little opportunity to prove Basin Range faulting and where the ore bodies have undergone very little displacement.

Two small offsets were noted in the Swansea vein during the earlier survey. (See p. 255.) A postmineral fault was noted during the recent survey in the Colorado mine 400 feet north of shaft No. 1, where the ore body is crossed by a brecciated zone with apparent downfaulting on its north side. Postmineral slickensides were seen along the "east limit" and several parallel north-south walls in the South Carolina stope of the Centennial Eureka mine and in the principal cross breaks of the same mine. Similar evidence of postmineral disturbance was noted in the gold stope of the Victoria mine and along the large brecciated zone called "the dike" in the Mammoth mine; but no great displacement could be proved at any of these places.

The one recognized Basin Range fault zone in the East Tintic district is mentioned in the descriptions of topography and of the volcanic rocks (pp. 16, 44, and 46). It lies along the valley that extends north-northeastward from Silver Pass and is marked by a series of step faults that have raised the base of the Packard rhyolite from the level of the valley up to the crest of the ridge. The topography of the district suggests other possible Basin Range faults, but none have yet been confirmed by structural evidence. Topography, however, can not everywhere be accepted as a criterion of recent faulting, for the prominent Eureka

and Mammoth gulches are associated only with faults formed before the period of ore deposition.

SUMMARY OF FAULTING.

Faulting in the Tintic district took place during five periods—(1) during folding, (2) after folding but before volcanic activity, (3) during volcanic activity, (4) soon after volcanic activity but before mineralization, and (5) distinctly later than mineralization. These periods were not all sharply separated from one another, and movements along some faults are known to have taken place during more than one period.

1. The earliest faults recognized are principally compression faults formed by the folding forces after the shapes of the folds had been determined. They include local overthrusts and accessory easterly faults along the quartzite and shale contact, and three or more strong northeast and two northwest faults in the limestone area. The shale was so flexible that, with one exception, none of the faults crossed from limestone into quartzite. The movement of blocks along all these faults appears to have been generally eastward, involving a considerable horizontal and some upward displacement. Northerly faults also were probably formed but can not be distinguished on the surface. A number of easterly faults in the limestone were also formed, some accessory to the northeast faults and others more closely connected with eastward bulges in the quartzite.

2. After the period of folding the tendency of the rocks, now relieved from compression, to reexpand, a gradual loss of frictional heat, and a gradual isostatic readjustment all contributed to the development of tensional or normal faults. The faulting took place chiefly in northerly and easterly directions and was marked by the settling of certain blocks and the tilting and convergence or divergence of adjacent blocks. Such faults can be proved only where exposures are abundant and otherwise favorable for their detection, as in the area southwest and north of Eureka Peak; but there is no reasonable doubt that they are prevalent throughout the district.

3. The network of faults already formed and the general settling along them gave conditions favorable to volcanic eruption. The pressure that forced up the lava columns, besides prying apart the strata to some extent just north of Mammoth Gulch, was sufficient to cause further movement along existing faults as well as to produce new faults. Some of the displacements that may be attributed to this cause are marked by upward movement of blocks nearest the igneous bodies—for instance, the Sioux-Ajax fault and the obscure faults south and southwest of Robinson; others are marked by the more nearly horizontal movement of a block away from the intruding monzonite magma—for instance, the "parting" or "east limit" fault in the Opex and Centennial Eureka mines and the Emerald-Grand Central fault. The monzonite intrusion was also brought about in part by the stoping away of the upfaulted blocks, but stoping as a visible process of intrusion was subordinate to faulting.

4. More fissuring or faulting took place after the cessation of volcanic eruptions and affected both igneous and sedimentary rocks. It is attributed in part to contraction of the igneous rocks, especially the monzonite, and to the general recooling of all the rocks in the district; also to further settling movements to compensate for the great amount of lava poured out upon the surface, as well as to the isostatic readjustment that may have been going on ever since the cessation of folding. No faults of great displacement are known to have been formed at this time. The development of new open fissures, however, as well as the reopening of older faults, had a large influence in determining the courses of the mineralizing solutions, whose period of activity is believed to have followed shortly after that of the monzonite intrusion.

5. The final period of fissuring or faulting was that in which the Basin Ranges were developed. This period can not be sharply separated from that next preceding, and movement is known to be still in progress in some parts of Utah. Some of the Tintic ore bodies are cut by postmineral movements along older faults, and at a few places ore bodies have been clearly displaced; but at none of these places has the amount of faulting been great enough to interfere seriously with the following of ore bodies. At least one fault of the Basin Range type is known to exist within the Tintic quadrangle.

ROCK ALTERATION.

PERIODS.

There were three periods of rock alteration in the Tintic district—one before volcanic activity, one during and immediately after volcanic activity, and one distinctly later than volcanic activity and extending down to the present. It is advisable to discriminate between the effects of the different periods in order that the particular alteration associated with ore deposition may be distinguished from other kinds of no economic significance. Not every variety of rock alteration is an indication of ore.

ALTERATION BEFORE VOLCANIC ACTIVITY.

Alteration before volcanic activity includes the formation of chert lenses, dolomitization, possible minor sericitization of shale during the folding stage, and surface weathering.

CHERT LENSES.

Chert lenses and nodules are prominent at three distinct horizons—in the Ajax limestone, in a small part of the Bluebell dolomite, and in the Pine Canyon limestone. They are in no way an indication of ore, although the chert on fresh fracture is very similar to the fine replacement quartz in the siliceous ore deposits. The silica in the chert was deposited as part of the original rock, in the form of microscopic shells or sponge spicules, and was later concentrated into concretions or nodules along the bedding planes. Where the supply of silica was relatively abundant, nodules grew to a considerable size, and in many places two or more nodules were united into more or less lenslike forms. In the Pine Canyon limestone cherty beds lie above and below the coarse-grained limestone that has been so extensively replaced by ore; but the dense cherty beds, where they are in contact with the ore, form the impervious walls or roof of the stope and are not themselves appreciably mineralized. Furthermore, the chert is just as abundant in outcrops remote from ore as in the immediate walls of stopes. It is not impossible for ore to form in the cherty beds, but they are far less likely to carry ore than the coarse-grained noncherty limestone. Another indication that the chert is not a sign of ore deposition may be seen in the silicified outcrops east of the Black Jack iron mine, where quartz has completely replaced the Ajax limestone, with the exception of the chert lenses and nodules, which have undergone brecciation but are still recognizable. The silicification of fossils in the Gardner dolomite and later beds is believed to have been contemporaneous with the development of the chert lenses.

DOLOMITIZATION.

Dolomite, as shown in the descriptions on pages 28–40, is almost wholly confined to rather fine-grained crystalline beds, most of them showing fossil remnants and some of them cross-bedding. It is not limited to any special horizons of the sedimentary series but occurs throughout the series in contact with dense and shaly argillaceous limestones. The chemical composition varies with the texture of the rock. The presence of fossil fragments converted partly or wholly into dolomite is proof that the dolomite is secondary after calcite. The crystalline texture may also be secondary, due to the crystallization of dolomite after limestone, but the cross-bedding and the size of the fossil fragments show that the original sediment was of relatively arenaceous and porous character ("calcarenite") in comparison with the dense argillaceous limestones ("calcilutites"), which may be aptly termed consolidated impure limestone muds. The distribution of dolomite has no relation to degree of folding, to any kind of fracturing, or to ore deposition. An apparent exception may be the occurrence of veins and impregnations of white to pink dolomite spar, but these are distinct from the dolomite beds, are limited to the zone of mineralization, are found in dolomites and argillaceous limestones alike, and are clearly of later origin and contemporaneous with the ore deposits. The fact that a certain bed of the sedimentary formations is dolomite has no bearing on the occurrence of ore. Some of the dolomite, where attacked by ore-forming solutions in favorably fissured portions, has been replaced by ore, but the bed that contains ore in one mine may be barren in another.

Dolomitization evidently took place before folding and fissuring and may have extended through an indefinite period from the time of deposition of the original limestone to the time of intense folding. The process evidently consisted of the submarine leaching of calcium

carbonate prior to consolidation, or of the replacement of the more permeable limestone beds on the sea bottom by magnesia salts dissolved in the sea water, or perhaps of both. The problem of dolomitization has been recently reviewed by Steidtmann,[1] who cites Högbom's studies,[2] which proved that calcium carbonate may be rapidly leached and any small amount of magnesium carbonate relatively concentrated. Steidtmann further points out that continual depletion of the calcium content of sea water by marine organisms tends to make solid (already deposited) calcium carbonate more out of equilibrium with sea water than magnesium carbonate, with the result that the deposited calcium carbonate tends to redissolve and the magnesium carbonate to become proportionately concentrated. He adds that if river waters of early Paleozoic time, by draining pre-Cambrian lands composed chiefly of granites and other rocks in which the ratio of magnesia to lime is relatively high, brought a much smaller proportion of calcium carbonate into the sea than is brought to-day the leaching of calcium carbonate by sea water must have been intensified. In regard to the replacement of calcium by magnesium in the sea, he cites articles by J. D. Dana, Branner, Skeats, and Judd, all clearly showing a replacement of the calcium in coral reefs by varying amounts of magnesium, and points out that the state in which the calcium exists, as well as the composition of the sea water, may influence the degree of change. Thus calcium carbonate, if crystallized as the less stable aragonite, which largely constitutes coral secretions, may be more easily replaced than if crystallized as the more stable form calcite. Again if the sea water is relatively high in magnesium salts (chloride, sulphate, or carbonate), the conditions will be more favorable to replacement of calcium carbonate by magnesium, which will augment the leaching of calcium already mentioned.

In the Tintic district from early Middle Cambrian until at least the end of Ordovician time limestones were being deposited, while sandstones and shales were forming nearer the shore line on the east. The rocks that furnished the sediments were pre-Cambrian granites, gneisses, schists, slates, and quartzites, and dissolved materials supplied from them to the Cambrian sea must therefore have been relatively high in magnesia. At the same time marine animals[3] were to some extent depleting the sea water of dissolved calcium, thus rendering conditions still more favorable for dolomitization. The more porous deposits on the sea bottom were permeated by the sea water, with its dissolved magnesian salts, and replacement or dolomitization was gradually accomplished, but the impervious beds of limestone mud were not appreciably affected and retained their original composition. As these beds, where interbedded with dolomite, are not thick or continuous over extensive areas, they did not form barriers to prevent the circulation of water in underlying porous strata, and the process of dolomitization may have continued during a long interval of time, approaching nearer to completion than would have been possible if the impervious beds had been thicker and more extensive. It is noteworthy in this connection that the Ajax limestone, lying just below the argillaceous Opohonga limestone, is less dolomitic than the formations below it, which are not interrupted by any extensive impervious strata. Analysis of a specimen from a coarse-grained bed near the top of the Ajax gave 52.34 per cent CaO and only 0.60 per cent MgO.

During the pre-Mississippian land intervals percolating ground waters may have contributed to the process of dolomitization, but there is at present no evidence, positive or negative, on this point.

The early Mississippian strata, those of the Gardner dolomite, were doubtless derived to some extent from the dolomitized Cambrian and Ordovician formations and may, to some extent, represent consolidated dolomitic sand; but in general they show the same relations between texture and composition as the Cambrian beds, and dolomitic composition therefore seems to be for the most part a secondary rather than a primary character. Fossils are larger and more conspicuous in these beds, and marine life may have had a correspondingly greater influence in promoting

[1] Steidtmann, Edward, The evolution of limestone and dolomite: Jour. Geology, vol. 19, pp. 332-338, 1911.

[2] Högbom, A. G., Ueber Dolomitbildung und dolomitische Kalkorganismen: Neues Jahrb., 1894, Band 1, pp. 262-274.

[3] Cambrian fossils, although scarce in the Tintic district, are numerous in the House Range and Blacksmith Fork sections. Their scarcity in the Tintic district may well be attributed to obliteration by the development of compression cleavage and by the recrystallization that accompanied dolomitization.

dolomitization than it did in Cambrian time. The presence of the coarse-grained nonmagnesian beds in the Pine Canyon limestone may appear too great an exception to prove the rule; these beds, however, not only alternate with dense impure beds but are overlain by the Humbug formation, which is composed largely of dense argillaceous limestone and shale and which where entire is from 5,000 to 6,000 feet or more thick. Their nonmagnesian character, therefore, accords with the hypothesis offered. It is quite possible that this thick and extensive formation was sufficient to cut off submarine circulation before the underlying porous beds could be appreciably dolomitized. If it was, the dolomitization, as already suggested, was a slow process, effected by the circulation of sea water through porous calcareous sediments, and continued to completion only when submarine circulation was not stopped by deposition of material that made a thick and extensive impervious formation.

Since the foregoing discussion was written Blackwelder[1] has suggested that the origin of the Bighorn dolomite may be due to the influence of calcareous algae. As there are some points of resemblance between the Bighorn dolomite and the dolomites of the Tintic district, Blackwelder's hypothesis may apply to a greater or less extent here and supplement the explanation already offered.

SERICITIZATION AND OTHER CHANGES DURING FOLDING.

The Cambrian shale or slate contains a conspicuous quantity of fine mica of sericitic appearance. This may be an original constituent derived from eroded pre-Cambrian schists and gneisses, but the original structure and texture of the rock at Tintic are so thoroughly obliterated by slaty cleavage and perhaps by recrystallization that the presence of original mica can not be readily proved. The mica scales now present are arranged parallel to the slaty cleavage—undoubtedly a secondary position; but whether they are the original fine mica rearranged or are of metamorphic origin, derived by the recrystallization of impure clay, can not be determined. In all probability both possibilities have in part been realized. This secondary sericitic mica in the slate, as well as along slickensided seams in the adjacent quartzite, is distinct in origin and significance from the sericite so extensively developed in the igneous rocks and bears no relation to ore deposition. The slate contains more mica than any other rock in the district, but, owing to its impervious character and the general absence in it of strong, continuous fissures, it is the most unlikely of all the rocks to contain bodies of ore in the Tintic district. In the East Tintic district, however, these same features, together with the nearly horizontal position of the strata, have served to concentrate ore minerals along the base of the shale, and where strong fissures cross the shale its less impervious beds and intercalated limestone lenses may be considerably replaced.

Fine grains of pyrite in small quantity may be present in the shale in the Tintic district, but these may have crystallized during or at the end of the period of folding and may have been derived from iron sulphide originally present in the rock rather than from infiltration of the ore-forming solutions. These products of recrystallization in the easily yielding slate during folding are not duplicated to any extent in the resistant quartzite, limestone, or dolomite, which instead underwent fracturing, shattering, and to some extent recementation of fractures by films of quartz, calcite, or dolomite. Quartz is the chief fracture filling in the quartzite, and the carbonates in the limestone and dolomite, but some fractures in the latter rocks, especially where silicified fossils and chert lenses are present, are filled with thin films of silica.

PREVOLCANIC WEATHERING.

The contacts between the effusive rocks and the sedimentary rocks show conclusively that the prevolcanic surface in the Tintic district was characterized by mountainous slopes as steep as those of to-day, if not steeper. Such a topography implies weathering to a pronounced degree, involving solution along certain limestone fractures, the development of caves, and the accumulation of kaolin with any other insoluble materials from the less pure beds. Kaolin of such origin may have accumulated especially along fault fissures, where crushed and shattered limestone could most easily be removed by downward-circulating waters, and

[1] Blackwelder, Eliot, Origin of the Bighorn dolomite: Geol. Soc. America Bull., vol. 24, pp. 607–624, 1913; A fully exposed reef of calcareous algae (?) in the Middle Cambrian of the Teton Mountains: Am. Jour. Sci., 4th ser., vol. 39, pp. 646–650, 1915.

the kaolin deposits, having accumulated, may later have served as barriers to the circulation of ore-forming solutions, thus accounting for ore bodies that end abruptly against fissures of premineral age. The effects of prevolcanic weathering are no different in kind from those of postvolcanic weathering, and there is no means of distinguishing between the two. Thus, where a cave is found, it can not be determined whether the cave was formed wholly before or since the volcanic period, or partly before and partly since. Kaolin-filled fissures appear the same, whether they were developed before or after the volcanic period or partly both. Although the deposits of the two periods of weathering can not be distinguished, their existence should be borne in mind in underground work, where, in case an ore body ends abruptly against a kaolinized or a tight fissure, it is necessary to ascertain whether the ore has been merely offset by a late fault or has been stopped by an older impervious break. The imperviousness of some breaks may be due to the earlier accumulation of kaolin; that of others may be due to premineral faulting which has brought an easily replaceable bed of limestone opposite a relatively nonreplaceable bed.

ALTERATION DURING AND IMMEDIATELY AFTER VOLCANIC ACTIVITY.

Alteration during volcanic activity is expressed in the sedimentary rocks, and perhaps to a slight extent in the volcanic rocks, by contact metamorphism, and in the volcanic rocks by widespread hydrothermal deposition.

Contact metamorphism is practically confined to the sedimentary rocks, especially the limestones. The only suggestion of it in igneous rocks comes from the presence of some microscopic colorless garnets in altered latite near the Dragon iron mine, but these may be of primary origin.

CONTACT METAMORPHISM OF QUARTZITE AND SHALE.

A quartzite inclusion in the monzonite southeast of the Mammoth switchback was found to contain a few crystals of garnet (probably almandite) along a bedding plane. Slate or shaly limestone is represented by a few inclusions resembling hornfels, one 200 feet southwest of the Robinson triangulation station and others (represented as one on the map) on the next spur to the southeast. This rock is nearly black, fine grained to dense, and obscurely banded. None of its minerals can be identified without the microscope. In thin sections the principal minerals, named in the order of abundance, are very fine muscovite (sericite), chlorite (pennine), quartz, zoisite, and magnetite. The muscovite and chlorite form a mat more or less interrupted by linear aggregates of quartz, which appear to preserve the original sedimentary structure. Zoisite is irregularly distributed in single hypautomorphic crystals and in diverging aggregates mixed with quartz. The magnetite forms small grains scattered throughout the section, but more abundant near and in the zoisite-quartz areas. These minerals show the rock to be high in SiO_2 and Al_2O_3 and to contain considerable MgO, CaO, and K_2O and a small percentage of iron oxides. This composition is near that of a limy shale or shaly limestone. Metamorphism caused the expulsion of carbon dioxide from the calcite originally present, the lime being left to unite with alumina and silica in the sediment and with water from the magma to form zoisite. There is nothing which definitely indicates the addition of any material from the magma besides water. The chlorite may be an alteration of metamorphic biotite, but it is so fine grained that its origin can not be definitely determined.

CONTACT METAMORPHISM OF LIMESTONE AND DOLOMITE.

The principal body of contact-metamorphic rock is in the limestone formations along the northeast contact of the monzonite. It extends continuously from Mammoth southeastward to the Dragon iron mine and thence northeastward, disappearing beneath the effusive rocks beyond the Carisa stock of monzonite. Its northern boundary is not sharply defined but as a whole follows a crescent-shaped course concave to the north. Besides this main body, there are within the monzonite a number of large inclusions which, to judge from recent exposures in tunnels and railroad cuts, are much more numerous than the obscure, disintegrated outcrops would indicate.

The outcrops as a whole are so much weathered and any faulting in them is so completely obscured that no serious attempt was made to study the metamorphism of individual beds of limestone or dolomite. The western part of the main body, if the original thickness of the rocks was maintained, includes the lower part of the Opohonga limestone and all of the Ajax

limestone and Opex dolomite; the large inclusions northeast of the Robinson triangulation station either represent sunken blocks of the same formation or are remnants of the Cole Canyon and Bluebird dolomites and possibly one or two still lower limestones.

The metamorphic effects are generally uniform in the inclusions and close to the main contact and diminish in intensity as distance from the contact increases. Evidence of intense metamorphism is limited to rocks within 400 or 500 feet from the contact, but rocks slightly affected may be found as much as 1,000 to 2,000 feet from any exposed contact. The most intensely metamorphosed variety is a dark-gray, brown-weathering dense rock, thoroughly crisscrossed by white hairlike veinlets of calcite and a white microscopic fibrous or platy mineral having the properties and composition of tridymite. A thin section of an inclusion in the tunnel just north of the Robinson triangulation station shows the principal minerals to be enstatite and spinel, with a few small grains of garnet and magnetite, interstitial calcite, and veinlets of tridymite and calcite in varying amounts. The enstatite, which was determined by its optical character, forms a few hypautomorphic crystals, about 1 millimeter long, partly surrounded by calcite, but it occurs mostly in a large irregular crystal that serves as a poikilitic groundmass for the spinel, garnet, and magnetite. The spinel is pale green to rather dark green and shows two imperfect cleavages at right angles. Some grains are isolated and approach octahedral and possibly dodecahedral outlines; but most of them form irregular aggregates intergrown with a little magnetite. Their color is that of the pleonaste or hercynite varieties. The spinel is slightly altered to a fine dustlike material resembling kaolin and is bordered in the altered places by small fibers that show a strong birefringence resembling that of calcite. Garnet is limited to a few very small yellowish-brown dodecahedrons of strong relief, most of them 0.03 millimeter, more or less, in diameter. Magnetite is practically limited to the intergrowths in spinel. Where the spinel is all weathered to kaolin (?) the magnetite appears nearly or quite unaffected. The veinlets consist mostly of interlocking aggregates of a fine platy mineral composed of silica and possessing a very weak birefringence characteristic of tridymite. In some places this mineral forms the whole veinlet; in others it is accompanied by an increasing amount of calcite. This mode of occurrence is very unusual for tridymite. Less commonly the calcite fills the whole veinlet. The kaolin is developed mostly along the edges of veinlets and to some extent around spinel boundaries in enstatite. This rock so far as its position in the field indicates may represent any of the strata from the Bluebird dolomite up to the Opex dolomite.

A second specimen, taken within 100 feet of the contact at Diamond Pass, is of the same type but altered—the pyroxene to serpentine and a little calcite, and any spinel to yellowish-brown limonite stains.

Outcrops along the contact northwestward from the Black Jack iron mine are characterized by a dark-gray rock composed almost entirely of coarsely crystallized calcite inclosing black octahedrons of spinel, few if any of which are over 1 millimeter in diameter. The rock is cut by minute veinlets of calcite. In the thin section studied one large crystal of calcite with multiple twinning forms a poikilitic groundmass inclosing spinel. The spinel forms irregular to octahedral grains as much as 1 millimeter in diameter and makes up about 50 per cent of the volume of the rock. Its color, yellowish brown in some larger grains and green in the others, suggests either the picotite, hercynite, or pleonaste varieties. The position of this rock type in the field suggests that it is a metamorphic derivative of some of the upper beds of the Opex dolomite.

Garnet, though scarce in the metamorphic rocks as a rule, forms local bunches, only one of which, in the railroad cut close by United States mineral monument No. 4, northwest of the Dragon iron mine, was seen. The garnet here is andradite. It is largely massive and nearly pure and also forms a few rather well formed crystals embedded in calcite. The outcrop was so completely surrounded by kaolinized débris that no structural features could be studied. The position of the garnet rock, like that of the spinel-calcite rock last described, is equivalent either to that of the upper beds of the Opex dolomite or to that of the lower beds of the Ajax limestone. Garnet and wollastonite have been reported from the metamorphic limestone around the North Star mine, approximately at the estimated boundary between the Ajax and Opohonga limestones.

A less severe degree of metamorphism is marked by recrystallization of the calcite or dolomite and destruction of the characteristic surface appearance of the rock. One specimen of the Opohonga limestone, taken about 800 feet northeast of Diamond Pass and 100 feet south of the spur crest, is of light-gray color, striped only where weathering has left fine powdery material along the more soluble layers. In thin section the rock consists mainly of calcite, relatively coarse grained (0.25 to 0.5 millimeter in diameter) and pure in some layers and relatively fine grained and crowded with minute crystals of diopside and possibly of mica in others. A very few minute grains of pyrite altered to limonite are present, and a little additional limonite fills short cracks. A little clouding, like that of kaolin, appears in one part of the section and is arranged in a network along minute reticulated cracks which spread from a place where clouding is strongest, suggesting an infiltration rather than a residue left by weathering. The same limestone farther north, close by United States mineral monument No. 1 and farther from the contact, is recrystallized into a very fine grained to dense rock, of light-gray to pale-yellowish or buff color. The characteristic banding is wholly obscured at this place but gradually appears as distance from the contact increases. The dense gray rock has a high content of magnesia, but it is not certain whether the specimen tested was taken from an originally dolomitic bed or not. In thin section fine carbonate grains make up the entire rock with the exception of a few minute limonite grains which appear to be pseudomorphs after pyrite crystals. No mineral containing alumina was noted, and any of the clay of the original rock must be uniformly scattered and hidden in the carbonate grains. Recrystallized carbonate with no visible silicates occurs also in the beds of coarse-grained limestone or dolomite found in the workings of the Lower Mammoth and the Dragon iron mine and along the railroad cut northeast of the Dragon open cut.

Metamorphism around the subsidiary monzonite stock at Sioux Pass is of the same character as along the main monzonite body. The surrounding rock in this locality is the Bluebell dolomite. Close to the contact the dolomite is changed to the pyroxene-spinel rock, colored pale brownish on the weathered surface. Farther from the contact the rock is recrystallized to a fine-grained grayish-white rock, and variations in color have disappeared; but the characteristic alternation of color gradually appears as distance from the contact increases. The effects of metamorphism along the northwest side of the stock disappear within 300 or 400 feet of the contact. This very narrow zone is in strong contrast to the much greater area of metamorphism south of the stock, which extends far enough to connect with a metamorphic band along the main monzonite mass. This distribution of metamorphic effects, together with the alignment of the two monzonite bodies, and the presence of several dikes of monzonite porphyry in the Iron Blossom No. 1 mine, is a strong indication, as stated on pages 59 and 64, that the monzonites are connected at no great depth.

The silicified outcrops east of the Black Jack iron mine have not been mentioned in this discussion of the metamorphic rocks, because the silicified rock, although within the metamorphic area, bears no definite relation to the contact and is believed to have been formed later, during the vein-forming stage. A thin section of this rock shows it to consist of fine cherty silica with a little intergrown pyrite and calcite. Some of the outcrops consist of a silicified breccia and appear to represent the cherty Ajax limestone, in which the chert lenses have been broken but not replaced, while the calcite and dolomite have suffered nearly complete replacement. Some of the silicified rock lies parallel to the bedding, and some appears to have replaced the limestone along fissures. The relations are not very clear, owing to the great amount of débris, which tends to isolate the silicified ledges; but in their structure, so far as exposed, and their composition they are more in accordance with the later vein deposits than with the earlier contact-metamorphic products.

Owing to the impossibility of a definite correlation of the metamorphic with the unaltered beds, no chemical analyses of the rocks have been made, but it is thought that rough calculations of composition will be sufficient to give a general idea of the changes involved.

To summarize the evidence of contact metamorphism, the rocks that have been

severely affected are for the most part dolomites or dolomitic limestones. The darker rocks (see pp. 28-34) when dissolved in hydrochloric acid have a small gray to black residue of clay, quartz, and organic matter; the lighter ones leave little or no residue. The following partial analysis of rock from one of the darker beds in the Cole Canyon dolomite, which is typical of the darker dolomites in general, is quoted from the earlier report[1]: "SiO_2, 8.77; Fe_2O_3, 0.49; MgO, 18.53; CaO, 27.22; CO_2, 41.77; total, 96.78 per cent." Alumina and organic matter should apparently account for the remaining 3.22 per cent not recorded. The total impurities, therefore, amount to about 12 per cent, at least half of which, according to the analysis and to microscopic study, must be quartz. It requires only a rough calculation to show that neither the enstatite-spinel nor the spinel-calcite rock can be derived by simple recrystallization of such a dolomite with only 12 per cent of impurities. If the spinel-enstatite rock is moderately estimated to consist of 60 per cent (volumetric) enstatite and 30 per cent magnesia spinel, with no account taken of the small amounts of garnet and magnetite, the alumina present will be sufficient to represent about 30 per cent kaolin in the original rock, and the silica will be sufficient to represent an additional 8 per cent of original quartz sand. In other words, only 60 per cent pure dolomite could have been present in the original rock, and this amount could not account for all the magnesia in the metamorphic rock. Furthermore, it has been shown by qualitative tests that, although beds of shaly limestone with a rather high alumina content are present in the district, such beds are not dolomitic. It seems, therefore, that silica and alumina have been introduced from the magma, though their relative proportions can not be estimated, whereas most of the calcite has been removed. If the garnet and magnetite were included in the estimate, they doubtless would indicate a small addition of iron oxide from the magma. The presence and arrangement of the tridymite-calcite veinlets indicate that some shrinkage took place during metamorphism, leaving cracks which were filled by later additions of silica and calcite.

The roughly calculated composition of the spinel-calcite rock also indicates an addition of alumina but gives a ratio of magnesia to calcite which could have been supplied by a dolomitic limestone. The absence of silica is in marked contrast to its presence in the spinel-enstatite rock. The beds that were simply recrystallized were evidently beyond the marked influence of any emanations of silica or alumina.

The general absence of metallic minerals is very striking and in marked contrast to their presence in most bodies of contact-metamorphosed limestone and dolomite. The only explanation of this condition that can be offered is that as the metamorphism took place near the surface and beneath a cover of volcanic rocks that were relatively permeable to heat the greater part of the materials, including the metals, that escaped from the magma at this time rose to higher levels than that represented by the present surface.

ALTERATION IN VOLCANIC ROCKS DURING VOLCANIC ACTIVITY.

If all changes in the volcanic rocks are considered, certain types of alteration, such as the recrystallization of brown hornblende phenocrysts into augite-magnetite-feldspar aggregates and the resorption of quartz and other phenocrysts, took place in the effusive lavas before their consolidation. The recrystallization of augite into hornblende in the monzonite and the replacement of feldspar by tourmaline in the Swansea rhyolite are evidently pneumatolytic changes that took place immediately after the consolidation of the respective rocks. These, however, are all microscopic features of interest chiefly to the petrographer.

Far more conspicuous is the widespread development of sericite, chlorite, calcite, and silica (quartz, chalcedony, or opal) in the volcanic rocks. Practically all specimens collected contain these minerals, at least in microscopic amounts, and many contain them in conspicuous megascopic masses. These minerals are so widespread that they can hardly be regarded as due solely to the solutions which deposited the ore bodies, although their origin appears closely related to that of the ore bodies. For example, the banded rhyolite east of the Iron Blossom No. 3 mine contains a considerable percentage of chalcedony and opal,

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 623.

especially along its flow lines, and the degree of silicification seems to be the same both near to and remote from any ore bodies. The Packard rhyolite throughout its extent also contains more or less secondary chalcedony and opal lining small cavities and calcite in openings along flow lines as well as throughout the rock. The intrusion of certain rhyolite dikes was accompanied by some silicification of the adjacent limestone. North of Eureka the main body of Packard rhyolite contains small pockets lined with heulandite. In one specimen from the East Tintic district tridymite is scattered through the rock and also lines cavities. The latites and tuffs also contain considerable opaline silica, which in some parts of the latite fills rather large cavities. In all the rocks the plagioclase feldspars are partly or completely altered to sericite with varying amounts of calcite and epidote and the pyroxenes and to a less extent the biotite are more or less altered to chlorite and calcite. Exceptionally plagioclase zones have been replaced by chlorite. Amygdules in some of the latite flows are also filled with chalcedony (or opal), calcite, and chlorite in varying amounts. Microscopic pyrite is commonly present with minerals replacing pyroxenes but is not conspicuous.

These minerals are characteristic of less intense propylitic alteration along the margins of mineralized fissure zones and were doubtless to some extent deposited by the vein-forming solutions, but their concentration in amygdules and along flow lines remote from strongly mineralized fissures suggests that they are rather the effects of fumarole action which extended throughout the volcanic period, the fumarole vapors and waters diffusing through the newly consolidated lava beds along flow lines, shrinkage cracks, and any other openings. The same secondary minerals are abundant in the intrusive bodies of Swansea rhyolite and monzonite, but here they are more closely associated with the metalliferous vein zones, and it thus becomes impossible to draw any line between the fumarolic alterations, which were going on throughout the volcanic period, and those accompanying the disposition of the metalliferous veins, which were formed after the consolidation and fissuring of the monzonite, the youngest of the important igneous rocks. It therefore seems reasonable to consider both alterations as belonging to one period, but whereas the widespread alteration of the effusive rocks was due to escaping water and gases in relatively small quantities and in various directions after each eruption, the more intense alteration accompanying the formation of the metalliferous deposits was effected by solutions which were concentrated at a considerable depth during the consolidation of the monzonite and which later ascended along certain strong fissure zones.

ALTERATION IMMEDIATELY FOLLOWING THE CLOSE OF VOLCANIC ACTIVITY AND ACCOMPANYING ORE DEPOSITION.

Alteration along the ore zones is common to igneous and sedimentary rocks, although the limestones and dolomites have been by far the most favorable of all for ore deposition. Alteration in the igneous rocks was most intense in and close to ore-bearing veins. Here the rocks, both monzonite and latite, were completely replaced by quartz and pyrite, accompanied in places by barite. Sericite is present, if at all, only in insignificant amount. A very little dolomite and calcite have also been noted, either lining cavities (that is, later growth than quartz) or in small outlying veins. Ore in the igneous rocks has been found only within these completely silicified zones. The margins of these replacement veins pass gradually into quartz-sericite-pyrite rock, whose original texture of monzonite or latite is distinctly preserved but whose feldspar and ferromagnesian minerals have been replaced by quartz, sericite, and pyrite. The solution thus far was rich in silica and contained enough potash to convert the feldspars into sericite, enough sulphur to change the iron in ferromagnesian silicates and magnetite into pyrite, and enough other ingredients, such as carbon dioxide, to dissolve out practically all the magnesia, lime, and soda of the original rock. As distance from the main vein increases this quartz-sericite-pyrite rock (bleached white on the weathered surface) passes into green or greenish-gray rock, in which feldspars and ferromagnesian silicates are only partly replaced by sericite, chlorite, epidote, calcite, and a little pyrite. Silica, either as quartz or chalcedony, is also present but as a rule is inconspicuous. The solution here furnished water to effect the hydration of the original minerals, but there has been no conspicuous removal or introduction of other material, with the possible exception of potash in

the sericite, and it is quite possible that some if not most of the sericite may be a soda mica. There has, however, been some transference of material, as is shown by short veinlets of chlorite and calcite.

In the dolomites and limestones the most intense alteration has been complete replacement of the wall rock by quartz accompanied by more or less barite and ore minerals. The passage of the quartz into unreplaced rock is on the whole abrupt, although not marked by a sharp, straight line. Near the margins of the silicified bodies and also above them dolomite and calcite "spar" are likely to be found. These two minerals are also present to a minor extent within the quartz bodies, where they are of distinctly later growth than the quartz. In some of the northern stopes of the Godiva and Iron Blossom ore zones, in the East Tintic Development vein, and in the North Tintic district dolomite and calcite are the principal gangue minerals. All these occurrences are comparatively remote from any known important intrusive bodies. Carbonate veins may be found a considerable distance from the main pay-ore deposits, and their distribution is in a way comparable to that of the less intensely altered (chloritized) igneous rock. They are characterized by dolomite in white to pale pink granular masses or in distinct rhombs where it lines pockets, and by calcite in columnar masses (travertine), or in long-pointed crystals (scalenohedrons) where it lines open spaces.

ALTERATION DISTINCTLY LATER THAN VOLCANIC ACTIVITY, DUE TO COLD DOWNWARD-CIRCULATING WATERS.

The effect of downward-circulating meteoric waters since the ore-forming period has been quite normal. In nonmineralized rock it has been similar to the effects of prevolcanic weathering—decomposition, leaving a residue of kaolin and more or less iron and manganese oxides, the formation of new caves, and the possible enlargement of older caves. In mineralized zones the acid solutions resulting from the decomposition of pyrite and other metallic minerals have hastened and increased the decomposition of nonmetallic minerals, leaving ultimate residues of kaolin and iron oxides, which in some places have accumulated in considerable masses. This is especially true where, during the erosion of overlying volcanic rocks, the decomposition products have been carried downward and replaced the underlying limestones or dolomites along their contacts or along fissures, thus producing what may be termed "false gossans," for they are no indication of the existence of other types of ore near by. In some places, most notably at the Dragon iron mine, enough limonite has collected in this manner to form a commercially important deposit of iron ore. The details of the process of concentration are given elsewhere (pp. 258–261). Calcite may accompany the limonite and psilomelane of these "false gossans," but it occurs either as crusts lining cavities or as flat rhombs or disklike crystals, in contrast to the long pointed scalenohedrons of calcite deposited by the vein-forming solutions. Flat rhombs perched upon the scalenohedrons have been seen in a few places.

In the main veins or channels of the igneous rocks downward-circulating waters have been effective down to ground-water level, or to depths ranging from 200 to more than 700 feet, leaving leached outcrops of limonite and iron-stained quartz, followed by oxidized ore. It has not been learned how deep complete oxidation has extended in the veins of the igneous rocks, but according to analyses much primary ore still remains above water level.

In the deposits in limestone, where ground-water level ranges from 900 feet in the Carisa to more than 2,000 feet (below the 1,800-foot level) in the Centennial Eureka and to still greater depths in the Mammoth and Grand Central, oxidation is much more extensive, and some large ore shoots have undergone extensive oxidation and enrichment down to their lowest extremities. The process of enrichment is considered fully in Part III.

SURFICIAL FORMATIONS.[1]

Mention has been made in preceding pages of the thick mantle of disintegrated rock material which covers so large a part of the Tintic area. This constitutes one of the most unfavorable conditions for geologic work and has often seriously interfered with the discovery of the indications of ore, yet the subject is one of interest and worthy of brief treatment in this place. These surficial formations have been

[1] This section is quoted substantially from the earlier report (Tower G. W., jr., and Smith, G. O., op. cit., pp. 666-680).

deposited in three different ways and may therefore be classed, with respect to origin, as alluvial, lacustrine, and colluvial.[1]

ALLUVIUM OF TINTIC VALLEY.

Tintic Valley is bordered by alluvial cones which extend down from every ravine and valley along the western edge of the Tintic Mountains. These cones of stream-deposited material become flatter as they emerge from the mouths of the ravines, and here better deserve to be termed alluvial fans. The slopes nearer the valley axis are gentle, although the grade is sufficient for the transportation of coarse material. The exceptionally large proportion of run-off, due to the frequent cloudbursts in this region, gives to these occasional streams a greater capacity for transportation than might be expected. The angularity of most of the rock fragments found near the middle of the valley also affords evidence as to the manner of transportation. Their journey from the rock slope to the outer edge of the alluvial fan has been comparatively rapid, and they have suffered less from the corrasion incident to transportation in a well-defined stream channel.

To a certain extent these alluvial fans are being trenched at present by deep arroyos, and this dissection affords opportunity for better examination of the alluvium of the valley. The structure is that characteristic for such deposits—a stratification locally imperfect but in general readily distinguished. Gravel and coarse sand are in many places interbedded. The freshness of all this detrital material is noticeable, for rock disintegration in the Tintic Mountains has been far in excess of rock decomposition.

In several places the alluvial deposits extend far up into the range, following the different drainage lines, and their distribution is therefore greater than can be represented on the geologic map. In sinking a well near Homansville alluvium was found to a depth of 65 feet, consisting of interbedded gravel and clay, the latter in beds a few inches in thickness. Another well was sunk over 250 feet before bedrock was reached.[2] The alluvium filling the valleys on the east side of the range is similar to that described above and does not require special mention.

LAKE BONNEVILLE BEDS.

Goshen Valley is about 1,000 feet lower than Tintic Valley and is covered by deposits of a different character. The Pleistocene lake which covered the eastern part of the Great Basin extended into this valley, and the fine material now covering the surface was deposited from the waters of Lake Bonneville. The alluvium, which doubtless covered the lower valley in pre-Bonneville time as it yet covers Tintic Valley, has been hidden from view by lacustrine deposits, which are finer grained and more evenly distributed.

The Bonneville shore line, which marks the highest water level, is well preserved at the head of Goshen Valley, at an elevation a few feet above the 5,100-foot contour. The terrace here is mostly cut in the alluvial material extending down from the small ravines which indent the mountain slope. As can be seen by reference to the map of the Bonneville Basin accompanying Gilbert's monograph,[1] this area formed a part of Utah Bay, an almost landlocked arm of the lake. Thus the waves which beat on this shore had but little fetch and were less efficient, and the shore line is not so deeply carved as at more exposed points, like the north end of the Oquirrh Mountains. Yet the terrace marking the Bonneville level is readily observed and is the more apparent because it forms the line of division between two types of topography. Above, the rock has been sculptured into bold outlines, which even the surface accumulations of rock detritus do not conceal; below, the lines are softened, and the gentle, smooth slopes of the lacustrine deposits afford a marked contrast even with the alluvial cones above. One interesting feature in the Bonneville shore is a bar constructed across a reentrant angle in the shore, forming a natural reservoir.

Faint traces of other shore lines can be detected, but at the level at which the water stood during the Provo stage the slope shows no break such as might be expected to indicate the Provo shore line, which is so strongly marked at other localities. There is, however,

[1] The term colluvial is applied by Merrill (Rocks, rock weathering, and soils, p. 319, 1897) to deposits of the nature of talus and cliff débris, in which gravity is the transporting agent.

[2] It is very possible that a considerable part of this material, especially in the deeper well, is thoroughly disintegrated rhyolite.—G. F. L.

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

within the limits of the Tintic quadrangle a conspicuous topographic feature which is connected with the Provo shore line. Currant Creek emerges from its canyon immediately east of the quadrangle, and from the mouth of this canyon there extends a large delta, which forms a noticeable interruption in the broad concave sweep at the head of Goshen Valley. The surface of this delta lies just above the 4,700-foot contour and thus approximates the level of the Provo shore line. Below, the delta face has a steep slope to the valley bottom. Currant Creek has now cut a deep channel in the old delta.

When the water stood at the Bonneville stage Currant Creek canyon was a narrow strait connecting the water in Juab Valley with that in Goshen Valley. With the fall of the lake level to the Provo stage there was a marked change of conditions. Currant Creek began to drain Juab Valley, having its point of discharge at the head of Goshen Valley. Here the delta was doubtless quickly built, and its upper surface may be taken as indicating the Provo water level. The uniform fineness of the material composing the Currant Creek delta is due probably to the fact that all coarser sediments were deposited in the lakelike expanse of the stream in Juab Valley above the canyon.

Sections of the wave-built terraces seen within the area show well-bedded sand, fine and well sorted. A few beds of coarse gravel a few inches thick are interbedded with the sand. These can be traced upward to the talus at the base of the steep slope of limestone and indicate alternation of conditions, the locally derived limestone fragments being deposited on the beach at some times and the finer shore drift at others. On the upper surfaces of the uppermost pebbles of these beds calcareous tufa has been deposited.

Dunes of drifting sand occur along the western edge of Goshen Valley east of the mouth of Pinyon Canyon.

TALUS DEPOSITS.

The group of talus deposits includes the rock detritus which occurs in the form of talus slides and avalanche streams. This material is heterogeneous and unstratified and owes its removal from the original rock mass primarily to the action of gravity. Creep, due to the action of frost and snow, may occur in these talus slides, and on the steepest slopes avalanches of snow doubtless have been effective in the transportation of the rock fragments to lower levels. Well-defined avalanche streams occur in some of the sharply cut V-shaped ravines, making the cross section resemble more the letter W, with the central ridge considerably lower than the sides. These rock streams have apparently not yet come to rest, to judge from their comparative lack of vegetation.

The mantle of talus material has accumulated to a great thickness in many places on the slopes of the Tintic Mountains. Both in the limestone areas and on the hills of monzonite prospect tunnels show this disintegrated rock to cover the solid rock to depths of 50 and even 100 feet. So compact is this unconsolidated material that roof and walls remain standing untimbered for many years in these deserted tunnels. In gulches where stream erosion has cut trenches in the débris the high angles at which the walls stand also show a considerable degree of cohesion in this material.

The occurrence of such large amounts of talus material is a phenomenon resulting from the climatic conditions. Physical disintegration of the rock mass is rapid on these barren slopes, exposed at this altitude to sudden and considerable changes of temperature. The amount of loose material thus furnished is too great for the agents available for its transportation. Accumulation has thus continued until on the lower slopes a balance is reached where the mantle has become in great part protective. On the steepest slopes, however, gravity is effective in the removal of the rock fragments, and additions to the talus accumulations below still continue to be made.

The cementation of the loose fragments and sand into such coherent masses is a process also connected with the aridity of the region. Chemical decomposition of the products of weathering is slight. Sufficient water does not circulate through these deposits to thoroughly leach out the soluble parts of the rocks, and what water is present is without doubt a less active solvent than that charged with the humus acids, such as would be present were the region covered with vegetation. However, a certain amount of solution does take place, though the dissolved material may not be removed far. Capillarity brings such solutions to the surface, and on evaporation the salts in solution are

left near the surface and here act as a cement. This calcareous cement is readily noticed in many of the deposits of this nature and seems a sufficient explanation of their exceptional compactness.

GEOLOGIC HISTORY.

The geologic history of the Tintic district is sharply divided into two groups of events—(1) sedimentation, folding, and erosion; (2) volcanism, Basin Range uplift, and erosion. The beginning of sedimentation is not recorded, as the base of the Tintic quartzite is not exposed. The quartzite may in part be of pre-Cambrian age, and in that case sedimentation progressed with no apparent interruption into Cambrian time. An unconformity, however, is known to exist at the base of the Cambrian in the Wasatch Mountains. The uniformity and general purity of the quartzite point to littoral marine rather than continental sedimentation. According to Walcott[1] the Cambrian shore line receded eastward, and, as littoral gave way to offshore conditions, the deposition of sand was followed by that of finer sediment, forming the shale. Owing to the migration of the shore line and perhaps also to undulations of the Lower Cambrian land surface, the age of the shale varies from place to place. In Nevada and western and central Utah its lower part is Lower Cambrian and its upper part Middle Cambrian; in northern Utah it is all Middle Cambrian. Its age in the Tintic district may correspond to either of these. The deposition of shale alternated somewhat with that of argillaceous limestone and finally gave way to it as subsidence continued. Further subsidence was marked by the accumulation of nearly 900 feet of argillaceous limestone, most of it distinctly shaly and some oolitic. Conditions then changed so as to permit the accumulation of calcium carbonate, composed mostly of shell remains and almost free from argillaceous or sandy matter but accompanied by considerable organic matter, which accounts for the present prevailing dark colors of the rocks and also for the fetid odor so characteristic of most of them when newly broken. The distinct though not prominent cross-bedding in these beds shows that although they were too far removed from shore to receive any conspicuous amount of clay, they were nevertheless deposited in places shallow enough to be affected by wave action.

These conditions continued during the deposition of the Bluebird and Cole Canyon dolomites, or to the end of Middle Cambrian time and probably during the early part of Upper Cambrian time. The shaly and cross-bedded members of the Opex dolomite, however, show that a part of Upper Cambrian time was marked by oscillations of a shallow sea bottom. These oscillations culminated in a slight emergence giving rise to erosion and the local deposition of conglomerate and quartzite, which mark the base of the Ordovician. The local unconformity thus produced may account for the much smaller thickness of Upper Cambrian strata in the Tintic district than in the House Range.

The first stage of Ordovician time was marked by subsidence and the deposition of the relatively nonargillaceous but siliceous Ajax limestone, the silica of which was presumably derived from sponge spicules and microscopic shells and is now represented in concentrated form by the lenses and nodules of chert. The deposition of siliceous limestone gradually gave way in early Ordovician time to that of argillaceous limestone (the Opohonga) and this was followed, still in early Ordovician time, by renewed deposition of nonargillaceous limestone (the Bluebell dolomite).

Deposition of the last-mentioned type continued with no apparent break through the remainder of the Ordovician period and possibly until the Upper Devonian; but the thickness of strata laid down in the Tintic region was much less than at other places in the State, and it is possible that most or all of the Silurian and Lower Devonian are represented by a concealed unconformity. The Upper Devonian was marked by the deposition of shaly limestone.

At some time during late Devonian or early Mississippian time the newly formed sediments were elevated above sea level over a considerable part of Utah. This uplift was followed by a period of erosion, sufficient in the Tintic district to remove the Devonian, possible Silurian, and Upper Ordovician and in some other places to remove all the Ordovician and much of the Cambrian limestones.

[1] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, p. 191, 1908.

In early Mississippian time this area was entirely submerged and covered by a great thickness of sediments. In the Tintic district the earliest Mississippian sediments consisted of a small quantity of siliceous material (the Victoria quartzite). derived either from some exposed portion of the Cambrian quartzite or possibly from an Ordovician quartzite now completely removed by erosion. This brief period of sandy deposition was followed by the Gardner epoch, in which nonargillaceous and argillaceous limestone were laid down alternately, and the Pine Canyon epoch, in which the deposition of siliceous and argillaceous limestone alternated with that of remarkably pure calcium carbonate (chiefly shell fragments). The Pine Canyon epoch marked the transition from early Mississippian (Madison) to late Mississippian time, which was characterized chiefly by alternating deposition of sandy, argillaceous, and calcareous beds (the Humbug formation).

Dolomitization and concentration of chert were going on in favorable strata during all the periods of sedimentation and probably also during the pre-Mississippian land intervals.

According to stratigraphic evidence in areas north of the Tintic district, sedimentation continued during late Mississippian and early Pennsylvanian time until the intercalated series of limestone, shale, and sandstone, of which the Humbug formation represents the basal beds, attained a thickness of at least 5,000 to 6,000 feet,[1] and this was followed by the deposition of at least 8,000 feet of quartzite (Bingham and Weber) in Pennsylvanian time.[2] An interruption of unknown though probably considerable duration and extent is marked by an unconformity at the top of the Weber quartzite, in the northern Wasatch country, but this was followed in that region by renewed sedimentation from late Pennsylvanian to the end of Jurassic time. There are no data to show how far Triassic and Jurassic deposits may have extended beyond their present western boundaries in the Wasatch country, but their thicknesses, there aggregating 3,640 feet, suggest that they may easily have extended as far southwest as the Tintic district. If they did, as much as 15,000 feet of late Paleozoic and Mesozoic sediments may once have overlain the rocks now exposed in the Tintic district.[3]

At the end of Jurassic time or in early Cretaceous time, according to evidence throughout the Cordilleran province, the Paleozoic and later beds were thrown into a series of folds. The local predominating thrust in the Tintic and North Tintic districts was from the west, developing the unsymmetrical and in places slightly overturned major anticline and syncline and the minor folds and contortions. The thrust was powerful enough and sustained enough not only to fold but also to fault the rocks. Faults formed at this time in the quartzite are local overthrusts along the quartzite-shale contact, accompanied by accessory easterly faults. Faults were doubtless formed within the quartzite, but they can not be proved, owing to the uniform appearance of the rock. The principal faults formed at this time in the limestone have general northeast and northwest trends; accessory faults trend east. Northerly faults may also have been formed in both quartzite and limestone.

After the period of folding—that is, during Cretaceous and probably early Tertiary time—readjustment of the earth's crust caused additional faulting along generally north and east directions and settling of fault blocks. Erosion also took place on an extensive scale, completely removing any Mesozoic and Pennsylvanian strata which may have been present, developing a mountainous topography quite as steep as the present, or even steeper, and bringing the first group of events in the geologic history of Tintic to a close.

The second part of the history was begun by a period of volcanic activity. The earliest eruptions recorded in the district, though not clearly exposed, were of latite or andesite. These were followed by the rhyolite eruptions. The extensive latite-andesite eruptions followed those of rhyolite and were closed by the monzonite intrusion, which may be equivalent to the

[1] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 377, 1895.

[2] Emmons, S. F., and Keith, Arthur, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, pp. 23, 35, 1905. The Bingham quartzite is estimated to be 8,000 to 10,000 feet thick. The corresponding Weber quartzite in the Wasatch Mountains has a maximum thickness of 5,000 to 6,000 feet, but its top, as shown by Eliot Blackwelder (New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 531–533, 1910), is marked by an unconformity.

[3] J. M. Boutwell (U. S. Geol. Survey Prof. Paper 77, pp. 49–59, 1912) has found 4,230 feet of strata (590 feet Pennsylvanian and 3,640 feet Mesozoic) above the Weber quartzite in the Park City and Big Cottonwood districts. This, added to the 6,000 feet of the "intercalated series", and 8,000 feet of Bingham quartzite, would give a total of 18,230 feet.

latest of the effusive flows. The flows were much more extensive than appears at present and probably covered the highest limestone peaks in the district. There is no means of fixing the exact age of this period in the Tintic district, but Smith[1] during the earlier survey found the latites, or andesites, to be later than conglomerate of probable Eocene age. This observation has been confirmed by the present writer, who has also found latitic or andesitic breccia resting upon fossiliferous Eocene conglomerate in the southern part of the Wasatch Mountains near Santaquin. The extensive flows of latites and the monzonite are therefore certainly of post-Eocene age. The age of the rhyolite can not yet be fixed with certainty but probably is not markedly earlier than that of the latites and monzonite.

Fissuring and faulting accompanied the volcanic eruptions and continued at intervals afterward. Just after the consolidation of the monzonite ore-forming solutions, concentrated during the consolidation, arose along newly formed fissures and deposited the original ore bodies in the sedimentary and igneous rocks. Ore deposition was in places accompanied and also followed by renewed or additional fissuring though no extensive faulting of the ore bodies took place.

Probably after the original ore bodies were formed (the exact time relations are not clear) the Tintic district, along with the greater part of Utah, was subjected to the Basin Range faulting, which tilted immense blocks and gave rise to the alternating mountain ranges and valleys that characterize the Great Basin. The elevation of these ranges was clearly later than the volcanic eruptions and must therefore have begun in middle or rather late Tertiary time. Elevation of some parts of the State is known to be still going on.

Erosion has been progressing without interruption during and ever since the periods of volcanic activity and ore deposition, carving the mountain peaks, canyons, and gulches and building alluvial cones out into the broad intermontane valleys. During one long stage of this interval, in Quaternary time, the climate was humid and the lowlands from Goshen Valley northward were covered by a part of the great Lake Bonneville, in which sediments derived from the mountains were deposited. A change to arid or semiarid conditions caused the almost total disappearance of this lake, of which Utah and Great Salt lakes are small remnants. The former extent of the lake is marked by unconsolidated lake beds in the flat valley bottom and by shore lines or terraces along the lower mountain slopes. During this long period of erosion and changing climate the newly formed volcanic rocks were gradually worn away, revealing the higher limestone and quartzite ridges and shrinking to their present areas. At the same time meteoric waters, circulating downward, attacked the ore bodies and began to concentrate them by transforming primary sulphides and related minerals into secondary sulphides and oxidized compounds. This process of enrichment is still going on.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 673.

PART II.—HISTORY OF MINING AND METALLURGY IN THE TINTIC DISTRICT.

By V. C. HEIKES.

PRODUCTION.

1869–1889.

In December, 1869, the first mining claim was located in the region that was subsequently organized into the Tintic mining district. This was the Sunbeam claim, in the southern part of the region. The district was organized early in 1870, but little work was done until the fall of that year. The Black Dragon, north of the Sunbeam, was discovered in January, 1870, and in February the Eureka Hill and Mammoth properties were staked. Deposits of lead carbonate rich in silver were being discovered daily, but it was difficult to get the ore to market. In 1871 the producing camps were Eureka, Silver City, and Diamond City.

The growth of the region was steady, and most of the early producers were still shipping ore 40 years later. Among the earliest prospects were the Mammoth, Armstrong, Martha Washington, Shoebridge, Swansea, Eureka Hill, and Showers. Even at that early date many kinds of ore were mined, including principally the carbonate and sulphide of lead, carbonate, oxide, and sulpharsenite of copper, and siliceous gold and silver ores containing small amounts of copper. These different kinds of ore led to complications in sale and treatment.

Owing to poor transportation facilities the development of the mines in the Tintic district for the first few years was not rapid. There was, however, considerable activity in mining the richest of the ores near the surface and shipping them to San Francisco, Cal., to Reno, Nev., to Baltimore, Md., and even to Swansea, Wales. Later most of the ores were shipped to Argo and Pueblo, Colo., and to the smelters in the Salt Lake valley.

The lower-grade ores were treated at mills and smelters in the district, at first with indifferent success, as the reduction processes then in use were not fully adapted to them. Ores taken from the immediate surface were handled with some success in amalgamation plants, but one of the greatest troubles is said to have been the abundance of antimony [1] in the ores milled, causing the mercury to flour. This was overcome to a large extent by roasting or chloridizing the ores. The progress of smelting and milling is considered on pages 114–117.

In 1875 the nearest railroad station to the camp was Payson, on the Utah Southern Railroad, 28 miles away, but a route was being surveyed through the West Tintic country for the Utah Western. The output of the district at that time consisted of silver bullion, lead bars, and copper matte, and the notable producers were the Eureka Hill, Bullion, Mammoth, Sunbeam, Bowers, Morning Glory, Showers, and Gold Hill. During the next three years there was no great change in production.

The building of railroads had a great effect on the output of Tintic, as the chief product of the camp has always been first-class shipping ore.

In 1878 the Utah Southern Railroad was extended southward to Ironton, 5 miles southwest of Eureka, and in the following year the output of the district nearly doubled. During this year (1879) the Crismon-Mammoth Co. marketed $12,000 worth of silver bullion. In the next two years the Mammoth and Tintic mills produced much bullion and the Eureka Hill was a regular shipper of ore. Amalgamation mills were not successful, as all the copper and half the gold and silver were lost. The Tintic mill, by chloridizing the ores, recovered $14,262 in gold and 87,223 ounces of silver, and the Bullion Beck mine became a notable shipper.

In 1883 the Salt Lake & Western Railroad,[2] as it was then known, handled 7,650 tons of

[1] Antimony is very scarce in the ores of the Tintic district proper but is abundant in the Scotia mine, in the West Tintic district, whose ore was treated at Homansville in the early days.

[2] This road connected at Ironton with the Utah Southern, which in 1890 consolidated with the Utah & Nevada, Utah & Northern, and Echo & Park City, under the management of the Union Pacific and the name Oregon Short Line. In July, 1903, the San Pedro, Los Angeles & Salt Lake Railroad (now Los Angeles & Salt Lake) took over this branch line of the Oregon Short Line from Salt Lake to Eureka, in connection with its through line to Los Angeles, Cal.

ore from the district. The road had been completed from Ironton to Silver City, and there was a branch to Mammoth. The American Eagle, Bullion Beck, Eureka Hill, and Mammoth were large shippers. During the next year (1884) the output of the district increased to 48,914 tons, of which 22,943 tons was shipped to smelters. At that time the annual production reached the million-dollar mark, and silver represented the greatest part of the value.

A large part of the ore shipped from the district at that time and later was oxidized and contained a large percentage of iron with a little gold and silver that made it valuable as a smelting flux. During 1887 about 33,300 tons of ore was shipped from various mines, including 10,350 tons of iron ore, and the Eureka Hill alone shipped 10,233 tons averaging 50 ounces of silver to the ton and 12 per cent of lead. Dividends were paid by the Mammoth, Bullion Beck, and Eureka Hill, but little was published concerning profits, either then or later. In 1887 and 1888 the value of all products was nearly $2,000,000 each year, and in 1889 it approached $3,000,000. The Centennial Eureka property, which has had a larger output than any other mine in the district, became an important producer, having begun shipping in 1886, at the same time as the Gemini.

At this time the district had four main producing areas. The southernmost was in the vicinity of Silver City, in the southern part of the district. The next to the north was the Mammoth Basin. The Eureka area, farther north, included the Bullion Beck, Eureka Hill, Centennial Eureka, and Gemini mines. East of the Eureka and Mammoth groups was the area of the Godiva, Uncle Sam, Humbug, Utah, and Sioux mines. In 1889 the production had increased to 46,075 tons, of which the Eureka Hill alone produced 18,500 tons. Tailings from the Mammoth mine were leached to advantage.

1890–1898.

In 1890 the value of the output was nearly double that of the preceding year, being over $5,000,000, from about 68,000 tons of ore. This was a record output at the time, and in fact it was larger than any subsequent year's output until 1899. As silver has been the main resource of the district, fluctuations in the price of the metal have seriously affected mining. From 1890 to 1901 the price of silver dropped from $1.05 to 60 cents an ounce. The silver output of the district was slightly decreased in 1891, and considerably so in the next two years.

The Rio Grande Western Railroad (now Denver & Rio Grande) entered the district in 1891, giving it the advantage of two roads. The ore output of the district in 1892 was about 47,000 tons, but production decreased in 1893. The value of the output remained close to $2,000,000 in 1893 and 1894. In 1895 there was an increase, particularly in gold and silver, which brought the value of the output up to about $3,000,000. Owing to the operations of the newly built quartz mills (p. 116), the value of the ore produced in 1896 rose to over $4,000,000. In 1897 there was a slight decrease in total value, due principally to a decrease in the output of silver, but the production of lead increased nearly 8,000,000 pounds. In 1898 crude ore, concentrates, and bullion were being shipped over the two railroads, and the product was valued at over $4,000,000. The leading producers were the Eureka Hill, Bullion Beck, Centennial Eureka, Grand Central, Mammoth, Star, Swansea, South Swansea, Eagle and Blue Bell, Humbug, Uncle Sam, and Joe Bowers mines.

1899–1914.

In 1899 the Tintic district was the leading mining center of the State in value of output, which was over $5,000,000. The shipping mines were the Mammoth, Bullion Beck, Centennial Eureka, Grand Central, Gemini, Eureka Hill, Swansea, South Swansea, Godiva, Humbug, Uncle Sam, Sioux, Sunbeam, Ajax, Star Consolidated, Four Acres, Carisa, Joe Bowers, May Day, Northern Spy, Eagle, Treasure Hill, Lower Mammoth, Tesora, Alaska, Showers Consolidated, Boss Tweed, Utah, Rabbit's Foot, and Silver Park. The Tintic (Dragon) iron mine shipped in 1899 nearly 600 cars of iron ore to be used as flux. Lead in 1899 had reached a production of over 38,000,000 pounds, and copper had increased to over 6,000,000 pounds. The annual production of the camp often exceeded that of Bingham until that district became the largest copper producer, and the records of many years showed Tintic outdoing Park City. In

spite of that fact, less was written with regard to the development of the region than about other equally productive mineral areas.

In 1900 an increase in gold, silver, and copper gave a total value of over $7,000,000, which was the record at that date and was not exceeded until 1906. The following year (1901) the production of all the metals except copper decreased, owing in great part to litigation. In 1902 there was a further decrease, resulting largely from the suspension of shipments from the Centennial Eureka mine. It was during that year that the American Smelting & Refining Co. and the United States Smelting Co. completed their plants at Murray and Midvale, Utah, where a large part of Tintic's ore was afterward reduced. By this time practically all the output was first-class shipping ore, most of the mills having served their usefulness. Great depth had been gained at many of the mines, and this same year a rich strike was made at the Gemini mine on the 1,700-foot level, then its deepest. Other mines that became large producers were the Ajax, Carisa, Lower Mammoth, Tesora, and Yankee Consolidated.

Conditions improved slightly in 1903, so that the output was valued at nearly $5,000,000 again, though the lead production was less. Fire interrupted work in the Eureka Hill and several adjoining mines, including the Centennial Eureka, which nevertheless was the largest shipper of the region. The value of the output in 1904 was nearly $6,000,000, from over 260,000 tons of ore, and there were increases in all metals except lead. Thirty-one mines shipped by way of the Rio Grande and Salt Lake railroads. In 1906 the unusually large production was valued at over $8,000,000. There was a big increase in lead, partly from the Beck Tunnel property, which furnished the sensation of the year. This rich lead ore came from a new area in the eastern part of the district. In 1907 ore valued at nearly $9,000,000 was marketed. The Colorado mine was a new and large producer of lead carbonate containing 93 ounces of silver to the ton and 35 per cent of lead. Lead carbonate was concentrated at the May Day mill, whose capacity was enlarged to 65 tons.

After the panic of 1907, production was greatly reduced in 1908. Prices were low and the smelting rate was high. Two copper smelters in Utah were closed. In 1909 mining had recovered and the district made a record output of lead, principally from the Colorado, Iron Blossom, Sioux, and Beck Tunnel mines. At the same time a modern ore-sampling mill was erected at Silver City. In 1910, 40 producers shipped over 300,000 tons of ore, valued at nearly $7,000,000, of which half was lead ore. The following year the output had nearly the same value. The Centennial Eureka alone shipped over 108,000 tons of ore.

The year 1912 was notable because the production was valued at nearly $10,000,000, the record of the district for all years. During that year the district became a zinc producer for the first time in its history. Mixed carbonate and silicate ores of zinc were shipped from the May Day, Uncle Sam, Lower Mammoth, Yankee, Gemini, and Ridge and Valley mines. In 1913 decreases amounting to about $2,000,000 were recorded in gold, silver, copper, and zinc.

TABLES OF PRODUCTION.

METALS.

The first of the following tables shows the quantity and value, by metals, of the ore sold or treated in the Tintic district from 1869 to 1916, inclusive. The annual production is shown beginning with 1877. The second table summarizes the production by decades. The third table shows the total production of the different ore zones, by metals, from 1869 to 1916.

The reports of output received from mining companies and those estimated by the Survey were nearly perfect for the Gemini zone. Several of the reports from mines in the Mammoth and Godiva zones were incomplete, but it is believed that the estimates come close to the actual output. The figures for the Iron Blossom zone do not include the large quantity of low-grade iron ore mined from the Dragon mine, but, with this exception, give a very complete record. Actual figures have been supplied for the igneous zone as far as they were available, and estimates for missing years are thought to be near the actual output of metal produced. The output of West Tintic and other outlying districts is included in the "undistributed" figures up to the year 1900. In the earlier years probably some other district totals of the ore production in Juab County were credited to the Tintic district.

Quantity and value of ore sold or treated in Tintic district, 1869–1916, and total metals recovered.

Year.	Ore (short tons).	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.[a]
		Quantity (fine ounces).	Value.	Quantity (fine ounces).	Value.	Quantity (pounds).	Value.	Quantity (pounds).	Value.	Quantity (pounds).	Value.	
1869–1876 [b]	....	24,730.00	$511,215	894,000	$1,139,580	2,558,228	$699,903	7,744,000	$549,540	....	....	$2,900,238
1877	....	[c] 2,000.00	41,344	[c] 150,000	180,000	[c][d] 313,200	59,508	[c][e] 294,496	16,167	....	....	297,019
1878	....	[c] 2,500.00	51,680	[c] 130,000	149,500	[c][d] 111,400	18,492	[c] 402,882	18,104	....	....	237,776
1879	....	[c] 2,500.00	51,680	[c] 250,000	280,000	[c][d] 110,800	20,669	[c] 1,206,466	49,465	....	....	401,754
1880	....	[f][d] 4,419.00	91,349	[f][d] 181,545	208,777	[c][d] 86,000	18,404	[c] 705,534	35,277	....	....	353,807
1881	....	[c] 2,332.00	48,207	[c][g] 151,073	170,712	[c][d] 300,000	54,600	[c] 451,810	21,687	....	....	295,206
1882	....	[c] 2,903.00	60,010	[d] 232,558	265,116	[c][d] 505,800	96,608	[c][e] 598,192	29,311	....	....	451,045
1883	....	[d] 2,000.00	41,344	[c][g] 523,798	581,416	[c][d] 281,885	46,511	[c] 900,000	38,700	....	....	707,971
1884	....	[d] 1,500.00	31,008	[c][g] 619,194	687,305	[c][d] 161,600	21,008	[c] 5,559,882	205,716	....	....	945,037
1885	....	[d] 868.00	17,943	[d] 868,925	929,750	[c][d] 198,000	21,384	[c] 7,784,759	303,606	....	....	1,272,683
1886	....	[d] 2,300.00	47,545	[d][e] 825,000	816,750	[c][d][e] 1,525,000	169,275	[c][e] 5,971,066	274,669	....	....	1,308,239
1887	....	[d] 3,200.00	66,150	[d] 1,412,463	1,384,214	[c][d] 2,000,000	256,000	[c] 6,337,991	285,210	....	....	1,991,574
1888	....	[d] 7,110.00	146,977	[d] 1,201,620	1,129,523	[c][d] 2,200,000	369,600	[c] 5,854,261	257,587	....	....	1,903,687
1889	....	[d] 11,940.00	308,837	[d] 2,055,700	1,932,358	[c][d] 1,870,000	252,450	[c] 9,978,559	389,164	....	....	2,882,809
1890	....	[d] 24,633.00	509,209	[d] 3,801,700	3,991,785	[c][d] 868,960	135,558	[c] 10,881,908	489,686	....	....	5,126,238
1891	....	[d] 19,444.00	401,943	[d] 2,901,730	2,872,713	[c][d] 688,000	88,064	[c] 13,147,645	565,349	....	....	3,928,069
1892	....	[d] 16,470.00	340,465	[d] 2,011,642	1,750,129	[c][d] 966,777	112,146	[c] 9,431,527	377,261	....	....	2,580,001
1893	....	[d] 15,097.00	312,083	[d] 1,990,860	1,552,871	[c][d] 320,000	34,560	[c] 7,063,209	261,339	....	....	2,160,853
1894	....	[d] 18,066.00	373,457	[d] 2,582,033	1,626,681	[c][d] 820,000	77,900	[c] 8,056,635	265,869	....	....	2,343,907
1895	....	[d] 27,525.00	568,992	[d] 3,517,166	2,286,158	[c][d] 1,574,000	168,418	[c] 11,283,504	361,074	....	....	3,384,642
1896	....	[d] 40,470.00	836,589	[d] 3,955,843	2,689,973	[c][d] 3,005,000	324,540	[c] 13,217,833	396,535	....	....	4,247,637
1897	....	[d] 37,038.00	765,643	[d] 2,877,600	1,726,560	[c] 2,500,000	300,000	[c] 21,341,802	768,305	....	....	3,560,508
1898	....	[c] 38,136.00	788,341	[c] 3,389,507	1,999,809	[c] 2,073,759	257,146	[c] 29,060,841	1,104,312	....	....	4,149,608
1899	....	[c] 44,917.00	928,517	[c] 3,329 833	1,997,890	[c] 3,441,677	588,527	[c] 38,080,904	1,713,641	....	....	5,228,575
1900	....	[c] 75,355.00	1,557,726	[c] 4,809,971	2,982,182	[c] 6,052,157	1,004,658	[c] 36,840,579	1,620,985	....	....	7,165,551
1901	....	[c] 40,159.00	830,160	[c] 2,685,735	1,611,441	[c] 7,557,825	1,262,157	[c] 24,388,133	1,048,690	....	....	4,752,448
1902	....	[c] 33,344.00	689,282	[c] 2,978,391	1,578,549	[c] 5,271,921	643,174	[c] 20,266,507	830,927	....	....	3,741,932
1903	....	[h] 65,987.00	1,364,072	[h] 3,620,362	1,954,995	[h] 8,023,464	1,099,215	[h] 12,481,040	524,204	....	....	4,942,486
1904	[h] 262,680	[h] 71,961.00	1,487,558	[h] 3,938,630	2,254,866	[h] 9,035,720	1,129,465	[h] 22,122,312	967,851	....	....	5,839,740
1905	[h] 266,761	[h] 100,942.00	2,086,656	[h] 3,951,348	2,386,614	[h] 10,982,751	1,713,309	[h] 18,702,573	879,021	....	....	7,065,600
1906	[h] 317,576	[h] 93,125.00	1,925,066	[h] 4,610,794	3,089,232	[h] 7,321,471	1,413,044	[h] 32,022,190	1,825,265	....	....	8,252,607
1907	[h] 278,504	[h] 113,065.44	2,337,270	[h] 4,949,082	3,266,393	[h] 7,755,831	1,551,166	[h] 33,019,242	1,750,019	....	....	8,904,848
1908	[h] 260,104	[h] 63,248.58	1,307,464	[h] 4,118,440	2,182,773	[h] 5,707,786	753,427	[h] 25,045,882	1,051,927	....	....	5,295,591
1909	[h] 256,578	[h] 83,189.47	1,719,679	[h] 6,404,847	3,330,520	[h] 5,915,669	769,037	[h] 56,502,209	2,429,595	....	....	8,248,831
1910	[h] 300,631	[h] 66,289.22	1,370,320	[h] 5,222,742	2,820,281	[h] 8,993,036	1,142,115	[h] 37,553,445	1,652,352	....	....	6,985,068
1911	[h] 360,391	[h] 79,015.54	1,633,396	[h] 5,514,702	2,922,792	[h] 10,922,154	1,365,269	[h] 23,572,966	1,060,784	....	....	6,982,241
1912	[h] 423,830	[h] 91,947.86	1,900,731	[h] 7,073,104	4,349,959	[h] 13,339,126	2,200,956	[h] 24,356,041	1,096,022	3,709,737	$255,972	9,803,640
1913	[h] 400,430	[h] 68,327.87	1,412,462	[h] 5,829,484	3,521,008	[h] 9,261,867	1,435,590	[h] 26,279,312	1,156,289	3,596,544	201,406	7,726,755
1914	298,486	46,139.60	953,790	4,666,944	2,580,820	5,290,471	703,632	36,510,911	1,423,926	758,217	38,669	5,700,837
1915	293,474	44,348.98	916,775	4,370,984	2,216,089	5,357,932	937,638	32,657,018	1,534,880	3,845,058	476,787	6,082,169
1916	365,949	41,382.57	855,454	5,113,566	3,364,727	7,106,645	1,748,234	39,294,351	2,711,311	3,711,156	497,295	9,177,021
Total [i]	....	1,532,925.80	31,688,389	119,712,919	78,762,811	152,375,912	25,063,297	716,970,477	32,341,622	15,620,712	1,470,129	169,326,248

[a] Average commercial prices used for each metal to make total for each calendar year.

[b] In December, 1869, West Tintic first attracted attention, and the Sunbeam mine was located. It became the first important producer later, along with the Scotia; then the Eureka Hill, Mammoth, Shoebridge, Martha Washington, Black Dragon, Black Eagle, and Swansea; all operated between 1870 and 1876. In 1873 the Mammoth-Copperopolis (Ajax) and Crismon-Mammoth mines were the principal producers of copper in Utah.

[c] Estimates by V. C. Heikes from a separation of the total output reported by the Director of the Mint, or given in the annual reviews of the Salt Lake Tribune and U. S. Geol. Survey Mineral Resources, 1882–1897. Parts of the records of some early producers were used in the estimates.

[d] Estimated by Tower and Smith (op. cit., pp. 615–616), who gave a table and remarks on production, 1880–1896: "It is thought the production of silver and gold previous to 1880 did not exceed $2,000,000 in value. From 1880 to 1896, inclusive, the production in gold has been 201,967 ounces and in silver 28,308,002 ounces. In addition to the silver and gold, Tintic has produced a large amount of lead and copper. The only method of calculation of the lead and copper is by finding the ratio of copper to either gold or silver. As silver is more uniformly distributed in the ores than gold, this metal has been chosen as the basis of calculation. The average content of copper and lead in 240,000 tons of ores was 0.6 per cent and 13.5 per cent, respectively. The ores which have furnished the basis of this calculation are the reported output of about two-thirds of the mines of the district. The content of silver of these same ores averages 52.50 ounces per ton. On this basis there are 20 pounds of copper to every 87.5 ounces of silver, and 20 pounds of lead to every 3.8 ounces of silver. Applying these ratios to the total production of the camp it is shown that there should have been produced 6,470,000 pounds of copper and 74,495 tons of lead for the years from 1880 to 1896, inclusive, thus roughly estimated. These calculations, however, judged from other standpoints, seem to be somewhat low for copper and high for lead."

[e] In 1877 the Eureka Hill mine commenced to produce silver-lead heavily; in 1882 the Bullion Beck & Champion mine became a silver-lead producer; and in 1886 the Centennial-Eureka mine, although not a large producer of lead, yielded largely gold, silver, and copper.

[f] Figures originally 3,012 ounces of gold and 8,682 ounces of silver, corrected from Tenth Census, vol. 13, p. 314.

[g] Tower and Smith (op. cit., p. 615) give, for 1880–1888, 682 ounces; 1881, 105,354 ounces; 1883, 224,800 ounces; 1884, 612,194 ounces. These figures have been corrected from producers' reports, the Eureka Hill being the largest producer for the years given.

[h] U. S. Geol. Survey Mineral Resources, 1903–1913.

[i] These totals are for mine output and aggregate more than if smelters' and refiners' figures were used.

Production of metals in Tintic district, 1869–1916, by periods.

Period.	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.
	Quantity (fine ounces).	Value.	Quantity (fine ounces).	Value.	Quantity (pounds).	Value.	Quantity (pounds).	Value.	Quantity (pounds).	Value.	
1869–1880	36, 149. 00	$747, 268	1, 605, 545	$1, 957, 857	3, 179, 628	$816, 916	10, 353, 378	$668, 553	....	....	$4, 190, 594
1881–1890	61, 786. 00	1, 277, 230	11, 692, 031	11, 888, 929	9, 911, 245	1, 422, 994	54, 318, 428	2, 295, 336	....	....	16, 884, 489
1891–1900	332, 517. 95	6, 873, 756	31, 366, 185	21, 484, 966	21, 441, 370	2, 955, 959	187, 524, 539	7, 434, 670	....	....	38, 749, 351
1901–1916	1, 102, 472. 76	22, 790, 135	75, 049, 158	43, 431, 059	127, 843, 669	19, 867, 428	464, 774, 132	21, 943, 063	15, 620, 712	$1.470,129	109, 501, 814
	1, 532, 925. 80	31, 688, 389	119, 712, 919	78, 762, 811	152, 375, 912	25, 063, 297	716, 970, 477	32, 341, 622	15, 620, 712	1, 470, 129	169, 326, 248

Production of Tintic district, by ore zones, including estimates, 1869–1916.

Zone.	Ore (tons).	Gold.			Silver.			Copper.		
		Quantity (ounces).	Total value.	Average value per ton.[a]	Quantity (ounces).	Value.	Average per ton (ounces).[a]	Quantity (pounds).	Value.	Average per ton (per cent).[a]
Gemini	2, 457, 169	681, 677. 53	$14, 091, 526	$5. 73	56, 002, 775	$38, 586, 035	22. 79	82, 981, 711	$12, 422, 909	1. 689
Mammoth	1, 777, 224	661, 099. 92	13, 666, 150	7. 69	26, 894, 114	17, 345, 888	15. 13	58, 948, 868	9, 442, 376	1. 658
Godiva	582, 937	70, 400. 93	1, 455, 316	2. 51	7, 675, 363	4, 473, 385	13. 21	13, 922, 960	2, 118, 563	1. 198
Iron Blossom [b]	628, 302	110, 122. 61	2, 276, 434	3. 62	19, 949, 163	11, 250, 751	31. 75	3, 806, 356	678, 485	. 303
Igneous	362, 827	8, 224. 81	170, 023	47	8, 932, 782	6, 899, 774	24. 62	2, 715, 383	400, 882	. 374
Undistributed	10, 000	1, 400. 00	28, 940	2. 89	258, 722	206, 978	25. 87	634	82	. 003
	5, 818, 459	1, 532, 925. 80	31, 688, 389	5. 45	119, 712, 919	78, 762, 811	20. 57	162, 375, 912	25, 063, 297	1. 395

Zone.	Lead.			Zinc (spelter).			Total value.	Average value per ton.	Total dividends.
	Quantity (pounds).	Value.	Average per ton (per cent).[a]	Quantity (pounds).	Value.	Average per ton (per cent).[a]			
Gemini	240, 763, 340	$10, 628, 310	4. 90	1, 576, 228	$189, 930	0. 004	$75, 918, 710	$30. 90	$13, 818, 400
Mammoth	115, 637, 779	5, 465, 449	3. 25	3, 466, 322	375, 146	. 098	46, 295, 009	26. 05	6, 623, 125
Godiva	159, 962, 039	7, 178, 137	13. 77	9, 081, 070	747, 040	. 782	15, 972, 441	27. 50	1, 755, 054
Iron Blossom [b]	149, 512, 059	6, 820, 561	11. 90	1, 479, 600	157, 101	. 118	21, 183, 332	33. 72	7, 097, 105
Igneous	45, 529, 594	1, 998, 710	6. 28	17, 492	912	. 002	9, 470, 301	26. 10	841, 914
Undistributed	5, 565, 666	250, 455	27. 83	....	....	....	486, 455	48. 64	....
	716, 970, 477	32, 341, 622	6. 16	15, 620, 712	1, 470, 129	. 134	169, 326, 248	29. 10	30, 135, 598

[a] General average of all kinds of ore produced in each zone. The zinc ore was produced from 1912 to 1916, inclusive. In 1912 it aggregated 6,306 tons, averaging 29.41 per cent of recoverable zinc; in 1913 it aggregated 6,265 tons, averaging 27.91 per cent; in 1914 it aggregated 1,064 tons, averaging 27.37 per cent; in 1915 it aggregated 7,029 tons, averaging 27.85 per cent; and in 1916 it aggregated 7,318 tons, averaging 24.84 per cent. The district has also produced 955 tons of lead-zinc ore. In 1913 it aggregated 335 tons averaging 9.64 per cent of lead and 14.78 per cent of recoverable zinc; in 1914 it aggregated 393 tons, averaging 11.34 per cent of lead and 21.83 per cent of recoverable zinc; and in 1916 it aggregated 227 tons, averaging 18.11 per cent of lead and 16.64 per cent of recoverable zinc.

[b] The Iron Blossom zone includes the output of the Tintic Standard zone since 1909, as follows: 6,728 tons of ore, 294.38 ounces of gold, 64,076 ounces of silver, 2,953 pounds of copper, 3,017,985 pounds of lead, 721,611 pounds of zinc, having a total value of $281,051, or an average value per ton of $41.77.

The tonnage and average grade of each kind of shipping product in the Tintic district during the 10 years from 1903 to 1913 are given in the following tables, in which the ore classification is necessarily arbitrary in part.

DRY OR SILICEOUS ORES.

The dry or siliceous ores comprise gold and silver ores proper, as well as fluxing ores carrying considerable quantities of iron and manganese oxides and very small quantities of gold and silver, and also ores carrying silver, lead, or zinc in quantities too low to classify them as copper, lead, zinc, or mixed ores. The contributors of the dry or siliceous ores for the period were the Grand Central, Victoria, Dragon (iron), Mammoth, Swansea, Lower Mammoth, Eagle and Blue Bell, Eureka City, Eureka Hill, South Swansea, Star Consolidated, Black Jack, Chief Consolidated, Hope, Garnet, Cornucopia, Windridge, Wyoming, Beatrice D., Mount Vernon, Iron Blossom, Brooklyn, Monterey, Gray Rocks, Centennial Eureka, Ajax, Iron King, Shoebridge, Showers, Sunbeam, Victor, Rabbit's Foot, Golden Treasure, and Tesora.

The Mammoth mine yielded the richest gold ores. The Dragon iron mine, as a shipper of iron-manganese ore used for flux, was a large contributor in 1906, 1907, 1910, and 1911. Its output ranged from 15,000 to 46,000 tons in the years mentioned, and the low average grade of its ore, estimated at about 40 cents in gold and nearly 1 ounce of silver per ton for those years, largely affects the average of the crude ore in the following table:

Dry or siliceous ore and concentrate, with average metallic content, produced in Tintic district and shipped to smelters, 1903–1916.

Crude ore.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	65,167	$11.27	13.66	0.64	0.29	$20.65
1904	52,809	9.56	13.83	.16	.61	18.51
1905	38,637	5.62	16.90	.49	1.23	24.83
1906	80,424	6.47	10.67	.31	.73	15.76
1907	34,282	15.11	6.53	.18	.07	20.19
1908	2,951	4.05	26.61	....	.45	18.54
1909	11,320	12.85	23.25	1.16	1.21	29.00
1910	66,204	2.50	5.59	.54	.17	7.04
1911	180,878	5.40	12.84	.89	.69	15.04
1912	193,083	5.26	17.37	.85	.43	19.15
1913	129,231	3.12	13.12	.55	.33	13.03
1914	102,704	3.47	9.67	.95	.33	11.67
1915	54,933	2.31	16.90	.61	.82	13.81
1916	79,194	2.14	11.25	.89	.09	14.04

Concentrates.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1904	825	$5.09	33.70	0.18	....	$25.08

COPPER ORE.

The copper ores include those carrying over 2.5 per cent of copper. A large contributor of copper ore near the grade mentioned was the Centennial Eureka mine; other mines, named in order of their importance as shippers of ore of this grade, are as follows: Carisa, Mammoth, Victor, Ajax, Laclede, Eagle and Blue Bell, Opohonaga, Bullock, Lower Mammoth, Gold Chain, Iron Blossom, Dragon, Eureka Hill, Brooklyn, Star Consolidated, Minnie Moore, Tesora, Grand Central, Homestake, Snowflake, Black Jack, Bullion Beck, Showers, Monterey, Argenta, Primrose, West Morning Glory, Shoebridge, United Sunbeam, Governor, Rabbit's Foot, Neibauer, and United Tintic. The average grade of the copper ore is shown in the following table:

Copper ore, with average metallic content, produced in Tintic district and shipped to smelters, 1903–1916.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	83,062	$6.79	17.30	4.00	....	$27.08
1904	116,838	7.78	13.24	3.55	0.003	24.54
1905	166,417	10.60	11.95	3.05	.001	27.40
1906	121,570	10.10	10.85	2.51	.028	27.21
1907	141,399	10.88	13.52	2.47	....	29.69
1908	111,194	9.99	15.47	2.39	.530	24.93
1909	119,480	8.71	12.12	2.29	.640	21.51
1910	87,334	8.25	9.68	4.08	.110	23.90
1911	69,014	5.75	12.61	5.42	.240	26.20
1912	126,079	4.67	10.99	3.69	.870	24.39
1913	146,994	4.33	8.33	2.44	.050	16.96
1914	61,377	4.90	10.13	1.94	....	15.67
1915	113,120	4.88	7.54	1.95	....	15.54
1916	115,043	3.67	9.49	2.32	....	21.31

LEAD ORE.

In general, the crude lead ore and lead concentrate are those containing over 4.5 per cent of lead. The most persistent producers of lead product of shipping grade during the 10 years were the Bullion Beck, Eureka Hill, Gemini, Lower Mammoth, May Day, Uncle Sam, Yankee, Eagle and Blue Bell, Ridge and Valley, Beck Tunnel, Black Jack, Mammoth, East Tintic Development, Iron Blossom, Centennial-Eureka, Chief Consolidated, Colorado, Godiva, Grand Central, Sioux, Eureka City, Clift, Ajax, Tetro, Joe Bowers, Martha Washington, Showers, Victoria, Frankie, Laclede, Star Consolidated, Victor, Silver Park, South Swansea, Shoebridge, North Clift, Windridge, Utah Consolidated, Plutus Consolidated, Salvator, Carisa, Susan, Swansea, Crown Point, Diamond Queen, Neibauer, Dragon, Tintic Standard, Gold Chain, and Rabbit's Foot.

Lead ore and concentrate, with average metallic content, produced in Tintic district and shipped to smelters, 1903–1916.

Crude ore.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	36,206	$1.45	33.28	0.60	15.26	$33.89
1904	62,289	.88	25.41	.46	16.24	30.76
1905	53,307	1.82	24.03	.43	25.50	41.78
1906	102,383	1.69	23.38	.33	14.19	35.03
1907	90,267	3.08	30.64	.34	17.30	43.01
1908	52,083	3.43	43.80	.38	21.92	46.06
1909	125,923	4.22	37.15	.07	21.00	42.31
1910	143,971	3.34	27.73	.41	12.74	30.55
1911	92,067	2.80	25.11	.13	11.11	26.42
1912	92,450	2.99	24.22	.25	10.81	28.44
1913	117,562	3.16	24.73	.30	10.72	28.45
1914	132,768	2.25	22.95	.35	13.45	26.37
1915	118,330	2.01	21.80	.11	13.38	26.04
1916	164,089	1.60	19.06	.11	11.89	31.10

Concentrates.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	416	$2.28	38.69	....	19.86	$39.86
1904	3,595	1.24	11.00	....	17.00	22.23
1905	1,409	5.95	20.03	....	20.10	37.06
1906	2,328	1.10	11.24	....	33.94	47.43
1907	2,593	1.11	13.87	....	37.75	44.97
1908	1,565	3.72	21.88	....	31.63	41.89
1909	881	3.28	21.90	....	30.45	40.86
1910	770	3.55	17.87	....	29.26	38.95
1911	574	2.45	15.93	....	25.20	33.57
1913	58	.48	8.40	0.19	24.03	27.29
1914	....	....	....	....	....	....
1915	155	....	27.42	....	17.81	30.64
1916	305	2.48	23.51	0.19	35.41	71.06

COPPER-LEAD ORE.

Copper-lead ore is classified according to the same method as copper and lead ores. The contributors of ore of this kind for the 10 years were the United Sunbeam, Undine, Shoebridge, Laclede, Carisa, Windridge, Mammoth, Opohonga, Silver Queen, and Bullock. The following table gives the production and assay of this ore:

Copper-lead ore, with average metallic content, produced in Tintic district and shipped to smelters, 1903–1916.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	388	$1.84	48.31	14.53	16.03	$81.21
1904	128	1.13	14.53	2.87	2.59	19.14
1906	485	1.49	27.11	3.82	16.00	52.90
1907	330	1.09	33.18	3.84	6.91	45.67
1908	24	.92	37.79	3.84	24.66	51.79
1909	46	.59	27.26	3.75	5.39	29.15
1910	42	1.26	16.24	7.61	16.14	43.54
1911	56	5.70	15.87	5.11	13.58	39.12
1912	472	2.53	128.14	3.49	8.13	100.18
1913	43	1.67	32.56	3.26	18.22	47.46
1914	180	.73	15.97	2.96	9.87	24.80
1915	62	.61	31.60	4.49	10.43	42.14
1916	78	3.44	52.52	3.45	11.39	70.63

ZINC ORES.

The zinc ores are those containing 25 per cent or more of zinc, irrespective of their precious metals. All the ore mined was a mixture of carbonate and silicate zinc ore. Contributors to the shipments of this class of ore were the Lower Mammoth, Uncle Sam, East Tintic Development, May Day, Gemini, Godiva, Ridge and Valley, Yankee, Chief Consolidated, Colorado, Beck Tunnel, and Iron Blossom.

Zinc ore, with average metallic content, produced in Tintic district and shipped to smelters, 1912–1916.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Lead (per cent).	Zinc (spelter, per cent).	Average gross value per ton.
1912	6,306	$0.33	1.36	1.91	29.41	$43.47
1913	6,265	....	....	....	27.91	31.26
1914	1,064	....	....	....	27.57	28.12
1915	7,029	....	.61	.34	27.35	68.53
1916	7,318	....	....	....	24.84	66.87

LEAD-ZINC ORE.

Lead-zinc ore is usually shipped by the buyer to manufacturers of pigment. In 1913, however, the shipments were purchased by producers of spelter, who sometimes save the residues of the ore containing part of the gold, silver, and lead content. The contributors of ore of this class were the May Day, East Tintic Development, Tintic Standard, and Uncle Sam.

Lead-zinc ore, with average metallic content, produced in Tintic district and shipped to smelters, 1903–1916.

Year.	Quantity (short tons).	Lead (per cent).	Zinc, spelter (per cent).	Average gross value per ton.
1913	192	9.45	23.29	$34.40
1914	393	11.3	21.8	46.29
1915	....	....	....	....
1916	227	18.1	16.6	69.72

SMELTING.

A small mill and a smelter were erected simultaneously in 1871 at Homansville, about 2½ miles east of Eureka. Owing to the refractory nature of much of the ore, milling was not a success and smelting was tried frequently. The first smelter built was the Clarkson, with two stacks, by the Utah Smelting & Milling Co., which started operations on June 17, 1871. This smelter turned out 172 tons of silver-lead bullion in 60 days. The ores smelted at these furnaces were from the Scotia (in the West Tintic district), Swansea, and Eureka Hill mines. After producing several hundred tons of lead bullion the plant was closed and moved away in 1872. Other smelting furnaces were erected at Diamond City and ran on ores from the Showers mine and other ores obtained by purchase. The material treated contained 50 per cent of lead and $80 in silver to the ton.[1]

Two Leetham furnaces were erected at Goshen in the fall of 1874 and ran at intervals for six months, producing 7½ carloads of bullion and 1 of copper matte. The furnaces, not being a success, were dismantled.

The Mammoth-Copperopolis built a smelting works in 1873 at Roseville, 6 miles from the mine, for the purpose of making black copper out of copper ores from the mine.[2] These works were in operation for several months, and at the time of the financial panic, when they were stopped, 126 tons of black copper, containing 90 per cent of copper and, including gold and silver, worth $252 a ton, had been shipped. The plant had two furnaces made of iron, with boiler-plate water jackets and a lining of fire brick made in Utah. Each furnace was built for a capacity of 12 tons of ore every 24 hours. The motive power used for the smelting plant was derived from the mill, 80 feet distant. Water was supplied from springs 2 miles distant and conducted to the works in galvanized-iron pipes. According to the Utah Mining Gazette of March 14, 1874, the Germania Smelting Co. erected furnaces in Black Dragon Hollow and later moved them to the vicinity of the Mammoth-Copperopolis mill; these are presumably the ones erected by the English company. Later in the year the furnaces were leased to the Crismon Bros., in whose mine, the Crismon-Mammoth, a large vein had been opened. At this time (1874), five furnaces and four mills were being operated in the district.

The Crismon-Mammoth Co. early in 1882,[3] after some experimentation, erected two matting furnaces, and when a trial had been made the 27-stamp mill belonging to the old company was closed and additional furnaces were constructed. Eight furnaces, each having a daily capacity of 8 tons of ore, were in operation in 1882. By this process 5 tons of ore was converted into 1 ton of matte at a cost of $60.

Ore from the Crismon-Mammoth and Mammoth-Copperopolis contained 35 per cent copper and 50 ounces of silver to the ton.

The number of furnaces was increased to 22 in all[4] during the early part of 1884 and a refinery was nearly completed, when the death of the principal member of the English syndicate that had purchased the property brought further operation to a standstill. The concern broke up, leaving a heavy indebtedness.

In the early part of 1886 some calcining furnaces, newly erected, were reported to be working well on Mammoth ore. The matte was shipped to Argo, Colo. In September of the same year these furnaces were pronounced a failure.

Nothing further is recorded of attempts at smelting in the district until 1908, when the Tintic Smelting Co. erected furnaces at Silver City for treating lead and copper ores from a number of mines controlled by the Knight syndicate. Before the end of the year two lead furnaces, each having a capacity of 250 tons, were operating, and a copper furnace was about ready to be placed in operation. Two additional lead furnaces, making four in all, were added in 1909 and operated until October. The lime and iron for flux were supplied from near-by quarries and mines of the smelting company, and as the ores of the district are of a siliceous nature fluxing conditions were ideal. Coke was shipped from Sunnyside, Utah. An average of 15 different slag samples taken at random is reported to have shown a loss of 1.7 ounces of silver to the ton and 0.7 per cent of lead.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 317, 1872.

[2] Raymond, R. W., op. cit. for 1873, p. 274, 1874.

[3] Director of Mint Rept., 1882, p. 257.

[4] Idem, 1883, p. 628.

This venture was the last of the attempts at smelting in the Tintic district. Although a success in smelting, the Tintic Smelting Co. was dominated by other more powerful interests and the lowering of smelting rates made it more profitable for the producing mining companies to ship to the smelters near Salt Lake. The smelter was dismantled in 1915.

MILLING.

The first mill in the district was started at Homansville in 1872 for the treatment of ores from the Eureka Hill mine by the amalgamation process. It was equipped with a Blake crusher and 12 revolving stamps having a capacity of treating about 25 tons of ore a day. Very little work was done by this plant, and it was finally removed to a site 8 miles south of the Mammoth mine, where it formed part of the 27-stamp mill constructed and enlarged between 1876 and 1879 to treat ores from the Crismon-Mammoth mine. The additional parts of this mill were obtained from other abandoned mills, the Ophir (Enterprise) furnishing 5 stamps and the Miller 10 stamps.

The second mill erected at Homansville was the Wyoming, built by an Ohio concern called the Wyoming Mining & Milling Co., which started January, 1873,[1] on ore from the old Wyoming mine,[2] afterward the Eagle and now part of the Eagle and Blue Bell. This mine failed, and the company bought others[3] and milled much ore. The Wyoming mill was equipped with 10 stamps, 4 amalgamating pans, and the first Stetefeldt chloridizing roaster furnace erected in Utah, which had a capacity of 30 tons. The mill is said by Col. Joseph M. Locke, its manager, to have been the only one that was successful at that time, as all the other mills tried to work the ores as free-milling ores, handling some ore from the immediate surface with a measure of success but failing with other ores. Antimony caused the chief trouble, which was overcome, according to Col. Locke, by thoroughly chloridizing it and then, with the aid of steam passed into the shaft of the Stetefeldt furnace, driving it off as chloride. The mill was not run steadily, owing to the scarcity of ore of the class which the mill could treat. The ore was mined usually in small lots by lessees and hauled to the mill, and when sufficient ore had accumulated to make a run the mill was put into commission. It ran in this way until 1878, closing then because its largest shipper, the owners of the Crismon-Mammoth mine, attempted to mill their own ore.

According to the ore record of the Wyoming mill, it treated from the Crismon-Mammoth mine between April 29, 1876, and June, 1877, ore aggregating 1,907 tons containing gold and silver. The average of 547 tons treated in 1877 assayed $11.74 in gold and 52.56 ounces in silver to the ton. As a general rule milling companies did not pay for gold until 1876, and as no assays were made by the miners except for silver the millman had the advantage. It was after this time that the mine owners attempted to mill their own ores.

In the spring of 1874 Col. Locke took charge of the Wyoming mill and, in February, 1877, he purchased it. The mill was afterward bought by the Tintic Mining & Milling Co., which began operations July 14, 1880. After this time the charges for working the ore were $25 a ton and the company guaranteed 80 per cent in bullion of the assay value of the silver and also of the gold if it exceeded $10 a ton. The product of this mill while under Col. Locke's management, from the spring of 1874 to the spring of 1878, was $39,058.73 in gold and $241,112.23 in silver recovered from 3,261.7 tons of ore.[4] In 1880 this mill was again put into condition for operation, and in 1881 it commenced on custom ores. It treated mostly Northern Spy ore in 1882, and operated almost continuously up to 1886.

In 1873, before the purchase of the Wyoming mill, the Tintic Co. built near Diamond a plant known as the Miller mill, with 10 stamps, wet crushing for custom work. Leaching[5] was unsuccessfully attempted here in the spring of 1879. Also in 1873 another plant, known as the Shoebridge or Ely mill, was built 6 miles south of Diamond for custom work. It had 15 stamps and 1 Aiken roasting furnace, and ran irregularly until February, 1877, when the company failed.[6] The Hunt & Douglas process was introduced in 1876. The property was

[1] Tenth Census, vol. 13, p. 446, 1880.

[2] Tower, G. W., jr., and Smith, G. O., op. cit., p. 739.

[3] Among them probably the Sunbeam, which, according to Col. Joseph M. Locke (statement made to G. F. Loughlin May 26, 1914), was owned by the company.

[4] Tenth Census, vol. 13, p. 446, 1880.

[5] Idem, p. 456. This report gives a full description of the mill.

[6] Idem, p. 458. This report gives a full description of the mill.

bought in 1878 by S. P. Ely, who ran it as a custom mill between October, 1878, and September, 1879. The process used at the mill, to a small extent, was to crush dry, roast with salt, treat by the Hunt & Douglas method for silver and copper, and then amalgamate in pans for gold. Sometimes amalgamation was performed first, and the tailings, if assaying over 12 ounces to the ton, were then treated by the Hunt & Douglas process.[1] As equipped the mill was capable of treating 10 tons of ore daily and was housed in a building 80 by 45 feet, containing six agitator tanks 9 feet in diameter and 5 feet high; six leaching tanks of the same size; five storage tanks above agitators, 7 feet in diameter and 6 feet high; three box vats for filters, 2½ feet square and 14 feet long; fourteen silver-precipitating tanks, 4 feet in diameter and 26 inches deep; and sixteen copper-precipitating tanks of the same size. The mill operators offered to purchase or work ore at 80 per cent of the assay value of the ore in silver and copper, plus 50 per cent of the assay value of the gold if over $5 a ton, less $25 for working.

The Mammoth-Copperopolis mill was erected at Roseville, 6 miles from the mine, to treat the gold ores of the mine, in 1873, about the same time or shortly before its smelter was constructed,[2] but it was soon found that the large quantity of copper present in the ore impeded operations very much. The equipment consisted of fifteen stamps of 750 pounds each, six amalgamating pans, three settlers, and one agitator. The mill had a capacity of 22½ tons of ore for each 24 hours.

The Crismon-Mammoth 27-stamp mill was built 8 miles south of the mine between December, 1876, and February, 1879, and crushed wet until March, 1880. A White & Howell furnace was then added but was soon shut down. Wet crushing was again begun in August, 1880. Besides a chloridizing roasting furnace there were seventeen 750-pound stamps, ten 550-pound stamps, a rock breaker, five pans, three settlers, and a retort. The tailings on hand in 1880 were said to assay $9 or more to the ton in gold and silver. The mill was closed in 1882.

In 1891 a 15-stamp mill was equipped by John Shettle to treat Mammoth ores by the lixiviation process. Forty tons was being treated daily, assaying 18 ounces of silver per ton, and 15 more stamps were being added.[3] This mill was sold to the Tintic Milling Co. in May, 1892, and worked Northern Spy ore averaging $20 in gold and silver to the ton.

Between 1886 and 1893 nearly all the mines were shipping ores to the smelters for treatment, and all ores not having sufficient value to warrant their transportation were accumulated on the waste dumps. As the district contained no water available for milling, it was impossible to make any use of these ores. However, during 1893 the Mammoth Mining Co. constructed a pipe line from Cherry Creek, a distance of 20 miles, and erected a large pumping plant, with a capacity of 600 gallons a minute, at a cost said to have been about $130,000. During the same year the construction of quartz mills was begun, and in 1895 there were four pan-amalgamation plants of the most modern type operating in the district—the Eureka Hill, 100 stamps, daily capacity 250 tons; Bullion Beck, roller mill and concentrating plant, daily capacity 200 tons; Mammoth, 60 stamps, daily capacity 180 tons; and Farrell or Sioux mill, 20 stamps, daily capacity 60 tons. The Mammoth and Farrell mills were at Robinson. They operated very successfully on the lower-grade ores of the district and shipped both bullion and concentrates. The richer ores were shipped to the smelters in the vicinity of Salt Lake City and elsewhere. Later the smelters and ore buyers offered better prices and the railroads lower rates on some of the ores that were being milled, making it an object to ship instead of mill, and so all the milling plants were soon closed.

In 1905 concentration mills were built on the Godiva and Uncle Sam properties, using water piped from Homansville, 2 miles away. The Uncle Sam mill reverted to the May Day Co. some time later. It was dismantled in 1916, and the building was used for storing ore. Attempts were made by lessees of the May Day property to concentrate the carbonate ore dry during the time the mill was in existence and resulted in a very good grade of cerusite

[1] Process described by R. W. Raymond (Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1875, pp. 395–410, 1877).

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1873, p. 274, 1874.

[3] Eng. and Min. Jour., Oct. 3, 1891.

concentrate. The process was that patented by Dietz & Keedy.

Beginning in 1913 the old ore and tailing dump of the May Day was treated in a cyanide plant operated by lessees. In the later part of 1913 a mill was completed at Silver City to use the Knight-Christensen process of chloridizing, roasting, and leaching, which was being adapted to treat the low-grade ores of the Knight mines—Iron Blossom, Colorado, Beck Tunnel, Black Jack, Dragon, and Swansea. The ores from these mines are said to afford an excellent variety of oxidized, sulphide, and siliceous material, from which to make a mixture most suitable to the process of treatment. On April 6, 1915, before certain mechanical difficulties could be overcome, the plant was destroyed by fire. Reconstruction began on the site of the abandoned Tintic smelter in July, 1915, by the Tintic Milling Co., newly organized by a consolidation of the Knight-Christensen Metallurgical Co. and the Mines Operating Co., which had operated successfully for two years at Park City, using the Holt-Dern process of roasting. The new mill was at first equipped with three Holt-Dern roasters and one Christensen roaster. The latter was discarded and eight more Holt-Dern roasters were added in 1916, when operations on a commercial scale began.

At first about 150 tons of ore was treated daily. This quantity was subsequently doubled. The ores treated contain silver as the principal metal, with copper, gold, and lead, the content ranging from 4 to 30 ounces of silver and 0.03 to 0.20 ounce of gold to the ton, 1 to 2 per cent of lead, and from a trace to 2 per cent of copper. The lead is not recovered. The sulphides from the Swansea mine provide, with the addition of powdered coal, the fuel necessary to the ore mixture in the chloridizing roast. Briefly the process consists in roasting a mixture of ores, salt, and powdered coal, condensing the acid roaster gases in salt solution, leaching the roasted ore with this solution, and precipitating the metals on scrap iron. About 13 cars of precipitate containing gold, silver, copper, and some bismuth have been shipped to different smelters, and 3 cars of bullion containing 800 to 2,000 ounces of silver and between 4 and 5 ounces of gold to the ton and 80 to 85 per cent of copper have been shipped to an eastern refinery.[1]

Tests were made at the Eureka plant of the Utah Mineral Concentrating Co., a concentration plant of 100 tons daily capacity built in the later part of 1914, by equipping it with rolls, tube mill, and Isbell concentrators. Low-grade ores from various parts of the Tintic district, and from the Chief mine especially, were intended for treatment in the plant. This plant was closed for an indefinite period in 1916 on account of financial difficulties.

[1] Interviews with Mr. George Dern, Dec. 22, 1915, and July 2, 1917. For detailed article showing flow sheet of Knight-Christensen mill, with illustrations and full description of process, see Met. and Chem. Eng., Dec., 1914, p. 757.

PART III.—THE ORE DEPOSITS.

By WALDEMAR LINDGREN.

LOCATION AND DISTRIBUTION.

The ore deposits of the Tintic district are found only in a small part of the East Tintic Range in which there are great areas of rhyolite, of monzonite porphyry, and of latite that are for the most part barren of ore deposits. The district proper forms a small area, mainly on the western slope, measuring about 4 miles from north to south and 2 miles from east to west. (See fig. 1, p. 15; fig. 15; and Pl. IV, in pocket.) It extends from Silver City to a point north of Eureka. There are, however, outlying areas that contain deposits of greater or less value. On the south prospects are found from Silver City to Diamond; on the east are the deposits of the East Tintic district, about 2 miles east of the divide of the range; on the north, about 9 miles from Eureka, are the Scranton mines of the North Tintic district, but in the same region there are large limestone areas practically barren of ore deposits.

The general mineralization reached its maximum in the area of monzonite east of Silver City—an area 1½ miles long and 1 mile wide—but in this vicinity there are few mines that have yielded a great production. The monzonite and adjacent parts of the other igneous rocks are extensively altered and impregnated with pyrite; these rocks are also traversed by a great number of fissure veins having a general northeasterly trend and steep dip, some of which have yielded considerable amounts of ore from their oxidized zones above water level. Among the mines on these veins are the Undine, Sunbeam, Martha Washington, Murray Hill, Silver Bow, and Swansea. The Swansea mine is in the intrusive Swansea rhyolite near the monzonite contact. There is no distinct line between the monzonite and the altered latite porphyry (in part, at least, effusive) on the east, and the veins cut both rocks. This mineral zone is 1½ miles wide from east to west, but very little work has been done on these deposits in the last 20 years. In most of the mines work was stopped when large quantities of water were encountered from 100 to 400 feet below the surface. The Swansea is the only one of these mines that has been worked below water level in recent years.

The sedimentary rocks north of the monzonite are not generally mineralized, but they contain a number of vein zones along which the limestone and dolomite are silicified for widths ranging from a few feet up to 200 or 300 feet. Outcrops of ore occur in places, but are neither continuous nor common and are confined chiefly to the southern part of the limestone area. The great mass of the sedimentary rocks is barren of ores and mineralization. The main mineralized zone of the monzonite crosses the contact at three places, but it is not possible at any one of these places to trace continuous outcrops, and the northward continuation of this zone forms the Mammoth vein zone in the limestone.

Four vein zones, of northward trend, are recognized in the limestone. For purposes of description these are called, beginning with the westernmost, (1) the Gemini zone, comprising, from north to south, the Ridge and Valley, Gemini, Bullion-Beck, Eureka Hill, and Centennial mines; (2) the Mammoth zone, comprising, from north to south, the Chief, Eagle and Blue Bell, Victoria, Grand Central, Mammoth, Golden Chain, Opohonga, Lower Mammoth, and Black Jack mines; (3) the Godiva zone, comprising, from north to south, the Godiva, May Day, Uncle Sam (Humbug), Utah, Northern Spy, Carisa, Red Rose, and North Star mines; and (4) the Iron Blossom zone, comprising, from north to south, the Beck Tunnel, Colorado, Sioux, Iron Blossom, Governor, and Dragon mines.

The Gemini zone does not cross the monzonite contact but is closely connected with the Mammoth zone in the lower workings of the

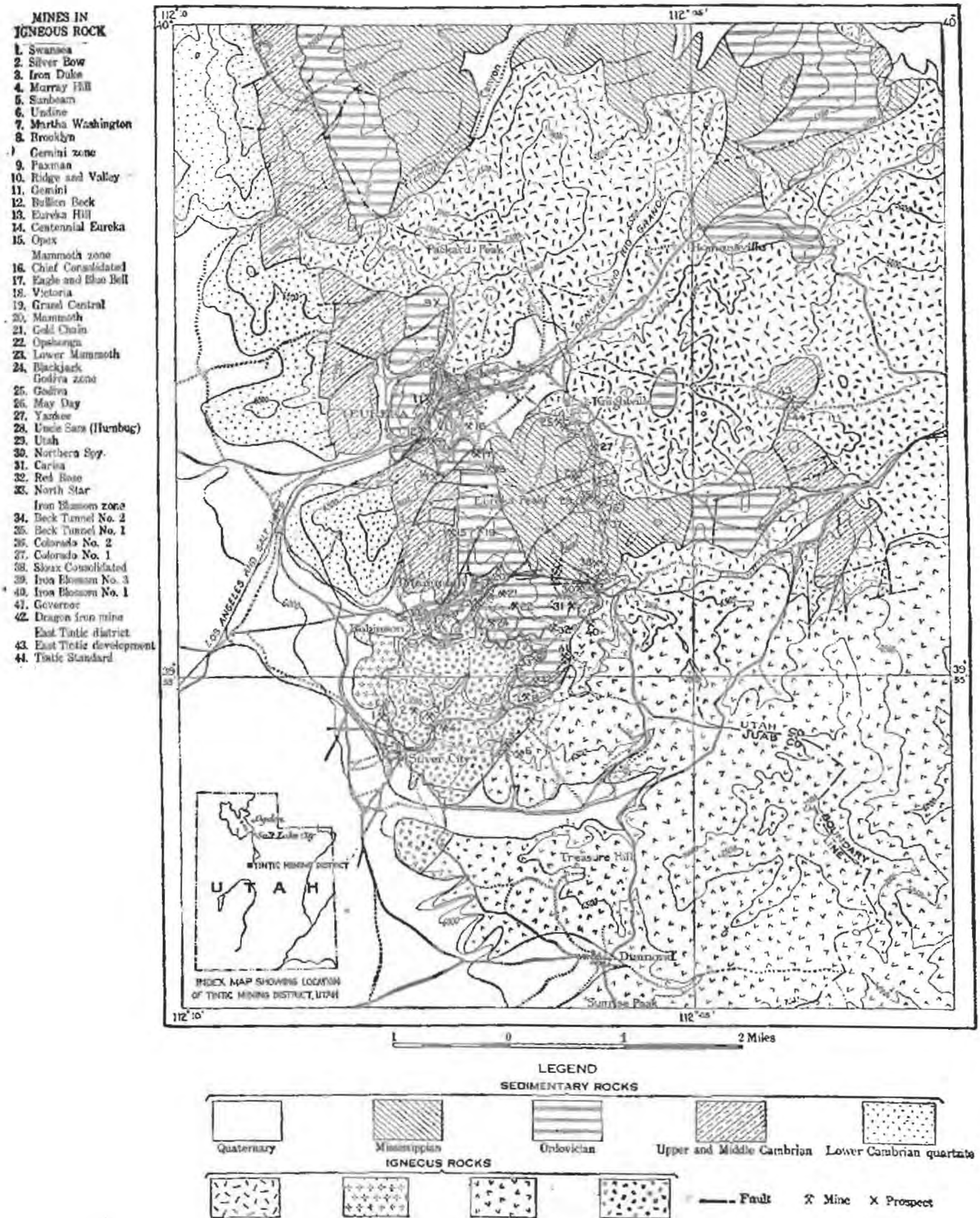


FIGURE 15.—Map of Tintic district showing principal formations and mines. (Adapted from geologic map, Pl. IV, in pocket.)

Centennial Eureka and Grand Central mines, as outlined in the following paragraph.

At a depth of about 1,700 and 1,800 feet in the Lower Mammoth mine a continuous vein crosses the contact into the limestone and has been moderately productive. A little north of the Lower Mammoth a series of north-northeasterly and northerly fissures carries the ore into the Gold Chain, Ajax, and Mammoth properties. The Mammoth is one of the most productive veins of the district. A lateral fissure a little to the west carries the ore on northerly fractures up through the Grand Central, Victoria, Eagle and Blue Bell, and Chief mines, all in the Mammoth zone. A westward-dipping fissure in the Grand Central carries the ore down to a depth of 2,200 feet, whence it communicates with the lower flat ore bodies in the Centennial and thence ascends in the two great ore columns of the Centennial, which follow strong easterly dislocations. From the upper levels of the Centennial the ore, now in the Gemini zone, is governed by northerly fissures, which carry it through the Eureka Hill, Bullion-Beck, Gemini, and Ridge and Valley mines. Much money has been spent in prospecting the limestone hills north of Robinson, but no success has been achieved; none of the northerly fractures appear to be ore-bearing south of the great easterly dislocations in the Centennial mine.

The Godiva and Iron Blossom ore zones lie east of the divide and are separated from the Mammoth zone by a belt of barren limestone three-fourths to 1 mile wide, which, where traversed by the Sioux-Ajax tunnel, proved almost entirely lacking in mineralization.

The Godiva ore zone crosses into the sediments 1,500 feet southwest of the North Star mine, though the outcrops are not continuous. It follows first a well-defined fissure system through the Red Rose, Carisa, and Northern Spy mines, turns northward, and is traced through the Utah, Humbug, May Day, Uncle Sam, and Godiva mines to a point where the barren rhyolite covers the limestone.

The Iron Blossom ore zone also does not crop out continuously, but it crosses the contact of monzonite and limestone at the Dragon mine and continues as a well-defined fissure vein through the Black Dragon and Governor claims into the great Iron Blossom property and thence through the Sioux, Colorado, and Beck Tunnel mines, north of which it has not been found, but near which it is connected by cross fractures with the Godiva ore zone. North of the Sioux-Ajax cross fault the deposit loses its vein character and follows the beds, which here lie flat, so that the ore body evidently represents the intersection of the northerly fractures with a limestone bed that was particularly susceptible to replacement.

RELATIONS OF DEPOSITS TO FRACTURES.

FRACTURES IN IGNEOUS ROCKS.

The relation of the ore bodies to fractures has been fully discussed in the earlier report[1] and is also referred to in Part I of this volume, so that brief comments will suffice here.

Tower and Smith observe that the fractures in the igneous rocks, particularly in the Swansea rhyolite and the monzonite near Silver City, in general trend N. 15° E. or N. 35° E.; a less number lie between those trends, and a few trend N. 70° E. or, as in the Swansea vein, a little west of north. Few of the veins that follow these fractures are persistent for long distances, but some of them are traceable for half a mile. Junctions and cross fractures are observed in places. Most of the fractures dip 75°–85° NW. or WNW. A few smaller deposits occur south of the Tintic district in the volcanic rocks of Sunrise Peak, from which this group of veins appears to radiate. The Packard rhyolite and the latite are irregularly fractured in the manner of flow rocks.

FRACTURES IN SEDIMENTARY ROCKS.

The fractures in the sedimentary beds are more complex than those in the igneous rocks, and they are present in all parts of the area, irrespective of mineralization. It is evident that by far the greater part of the fracturing and faulting antedates the epoch of mineralization, and in fact many of the fractures antedate the beginning of the volcanic period. Fractures and dislocations later than the mineralization are rare; some movements of this kind were observed along the easterly faults in the Centennial mine and were proved by the occurrence of polished faces of ore, but they merely represent slight recurrent movements along old fractures. Some of the most extensive faults had so nearly healed at the

[1] Tower, G. W., jr., and Smith, G. O., op. cit., pp. 677–683.

time of the genesis of the ore deposits that they had little or no influence on the course of the ore solutions. Of this character are the great faults in Eureka Gulch and some of those on the ridge south of that gulch. On the other hand, the Sioux-Ajax fault changed to a marked degree the form of the deposits of the Iron Blossom zone.

For the ore deposition the most important though not the most conspicuous fractures are those which trend approximately north and which generally have a vertical or steep easterly dip. These are especially abundant in the western part of the syncline, where the strata stand nearly vertical and where slipping parallel to the beds has taken place, but they also occur in the eastern part of the district, where the strata are flat. Some of these fractures intersect the beds at a very acute angle.

Fractures trending north-northeast are especially numerous in the vicinity of the Ajax and Mammoth, and the ores follow them alternately with the northerly fractures.

Fractures trending northeast to east and dipping 50°–70° S. are very common, and many of them are relatively open. In some places where the northerly fractures prevail—for example, in the Gemini and Eureka Hill mines—the ore locally follows these "cross breaks," as they are called in the district. The most conspicuous examples are the two great easterly cross breaks in the Centennial mine. South of these cross breaks there is no mineralization along the northerly fractures of the Gemini ore zone.

Ore-bearing fractures trending northwest or north-northwest are rare and usually stand in relation to the bending or offsetting to the west which is observed in Eureka Gulch, for instance, near the Bullion Beck mine and in the Victoria and Blue Bell mines.

Fractures striking N. 30° E. and dipping 60°–80° NNW. are of considerable importance in the Mammoth and Grand Central mines.

It is probable that the northerly fractures and most of the north-northeasterly fractures are of the same age and that they belong to a single fracture system which, beginning in the monzonite area, continues northward through the area of sedimentary rocks. South of the Sioux-Ajax fault, for instance, the ore-bearing fractures change in strike from north to north-northeast. Most of the mineralized "cross breaks" trending approximately east, were probably formed or reopened at the same time or a little later.

The greater dislocations have taken place along the northeasterly and easterly faults (see pp. 78-87); the movement along the northerly fractures is probably considerably smaller, though it can rarely be measured.

UNDERGROUND WATER.

GENERAL CONDITIONS.

In the limestone area the water level is unusually low and is found at a depth of 1,650 to 2,400 feet below the surface. One mine, the Mammoth, has not yet reached water at a vertical depth of 2,362 feet. On the other hand, in the monzonite water is ordinarily found within a few hundred feet of the surface. These unusual relations are caused by the complex and extensive fracturing of the limestone, which allows the water to sink to great depths.

The position of the deep underground waters of the region is controlled by the lowest level of discharge—that is, by the level of Utah Lake, at the foot of the Wasatch Range, at an altitude of about 4,500 feet. The water in the deep shafts is ordinarily found about 200 or 300 feet above this level.

The summit line of the East Tintic Range reaches 8,000 feet. At its easterly foot, 9 miles from the summit, lies Goshen Valley, at the foot of the Wasatch Range, at an altitude of 4,500 to 4,800 feet. On the west extends the Tintic Valley, which lies at an altitude of about 5,800 feet. In the thoroughly fractured limestone the water level thus lies extremely deep and has a very gentle slope to the northeast. The water appears to be irregularly distributed, and there are many local pockets high above the permanent level.

Another local water level is found in the rhyolite where it overlies the dry limestone. The lower parts of the Packard rhyolite are in places clayey and soft and are able to hold a considerable quantity of water which can be locally utilized for boilers. Still another local water level occurs at the bottom of the detritus that fills the valleys, such as Eureka Gulch and the valley near Homansville. The water found at this level is better suited for drinking than any other in the district.

QUALITY OF WATER.

The water in the monzonite and associated lava flows to the south of the district is usually of good quality except in the mines that contain much pyrite. Springs appear in places. No analyses of this water are available.

The shallow water in the rhyolite, found at 100 to 300 feet below the surface, contains in places much calcium sulphate, locally in such amounts as to interfere with its domestic and industrial use. Fairly pure water, however, is obtained in the detrital deposits in the upper part of Eureka and at Homansville, on the eastern slope. The wells at Homansville, which supply some of the mines, are from 100 to 265 feet deep, and yield a flow of 25 to 80 gallons a minute.[1]

An analysis of the water from the Eureka Hill pumping plant at Homansville gave the following composition, in parts per million:

Analysis of water from wells at Homansville, Utah.

[Made by the Dearborn Drug & Chemical Co.[2]]

SiO_2	60	HCO_3	163
$Al_2O_3+Fe_2O_3$	9.9	SO_4	65
Ca	44	Cl	48
Mg	29	Total solids	400
Na+K	65		

This is a relatively pure water. The amount of magnesia is unusually high.

The water from the deep levels in the limestone is fairly pure and does not contain any deleterious substances, such as lead, copper, and arsenic.

An analysis of the water from the Gemini mine in the shaft 1,650 feet below the surface gave the following result:

Analysis of mine water from 1,650-foot level of Gemini mine.

[Parts per million. Chase Palmer, analyst.]

Na(K)	75.6	HCO_3	265.2
Ca	115.9	SiO_2	24.4
Mg	21.5		760.0
Fe, Al	Trace		
SO	124.0	Total solids at 180°	718
Cl	121.4	Loss on ignition	78
CO_3	12.0		

The water contains no free CO_2 and no copper, lead, or arsenic.

Another analysis of the Gemini mine water, made by Herman Harms, of Salt Lake City, for the United States Smelting & Refining Co., gave 479 parts per million of solids dried at 100° C., including 178 parts per million of calcium carbonate ($CaCO_3$), 29 of magnesium carbonate, 17 of silica, 106 of sodium chloride, and 59 of magnesium sulphate.

An analysis of mine water from the 2,000-foot level of the Centennial Eureka mine, made by Mr. Harms, gave for total solids at 100° C., 408 parts per million, of which 106 was calculated as calcium carbonate, 17 as calcium sulphate, 74 as sodium chloride, 20.5 as magnesium carbonate, and 106 as magnesium sulphate.

Analyses of waters from both the Gemini and the Centennial mines are normal for sedimentary carbonate rocks in arid climates, and show no unusual constituents nor any in abnormally large quantities. There is relatively much magnesium and a much greater quantity of chlorine than is usually found in humid climates. The prevailing dolomites account for the large amount of magnesium.

WATER LEVEL AT THE MINES.

The position of the deep water level in the Tintic district is shown in figure 16, which gives three sections from north to south along the three principal ore zones over a distance of about 3½ miles. The Gemini zone has a comparatively high water level, standing at 4,813 and 4,851 feet in the Gemini and Centennial mines, respectively. Farther south in the Opex it sinks to 4,791 feet.

The water level in the Mammoth zone is 4,755 and 4,759 feet above the sea in the Chief and Grand Central mines, respectively; farther south, in the Mammoth, no water has been reached at 4,690 feet, and in the Lower Mammoth it is only reached at 4,682 feet, which so far is the lowest water level found in the district. It seems, therefore, as if the water stands at its lowest level in the vicinity of Mammoth Gulch, above Robinson.

The mines of the Godiva and Iron Blossom ore zones are situated at higher altitudes and water has been reached only in the Iron Blossom No. 1, in which it stands at 5,375 feet; but this is probably a local water level, for the water from the sump is carried by means of a hose into a diamond drill hole 500 feet deep, dipping N. 56° W., at the bottom of the shaft, and disappears in the hole. In drifting south along the bottom level flowing water was

[1] Meinzer, O. E., Ground water in Juab, Millard, and Iron counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, p. 85, 1911.

[2] This analysis was originally given in hypothetical combinations and in grains per gallon. All the carbonates were recalculated as bicarbonates by O. E. Meinzer (op. cit., p. 85).

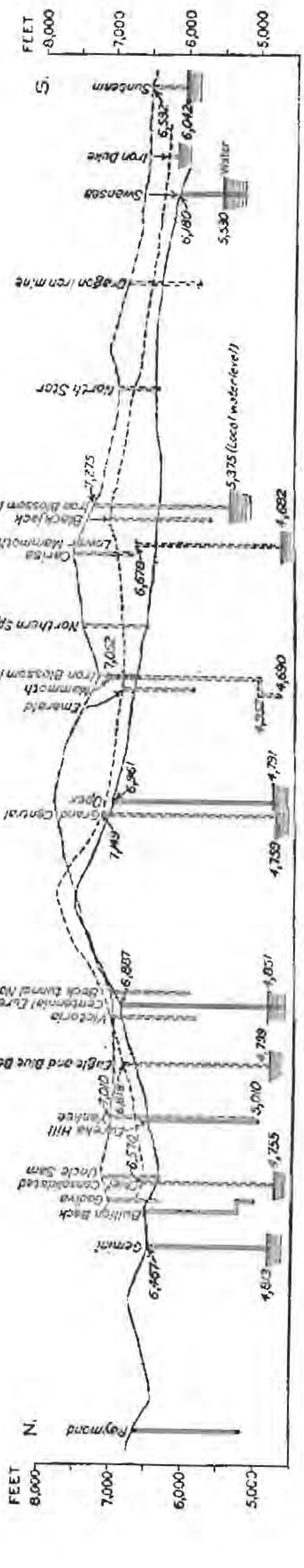


FIGURE 16.—Cross sections of Tintic district, showing shafts and water level.

encountered in limestone about 1,000 feet from the shaft. Water for drinking is pumped from a diamond-drill hole 1,139 feet deep, directed S. 54° E., also at the bottom of the shaft.

In the Dragon mine, which is the southernmost deep shaft on this line, no water was found at a depth of 1,000 feet, but drifts into the porphyry toward the south on the 800 and 1,000 foot levels soon encountered water flowing from fissures.

In the monzonite and porphyry area the water level ordinarily stands at a few hundred feet below the surface, or at altitudes from 5,500 to 6,000 feet.

QUANTITY OF WATER.

The water is generally encountered in large quantities and concerted action among mine owners will be necessary before any considerable advance below water level can be made.

In the monzonite and related porphyry the quantity of water encountered was large enough to stop mining operations. No ordinary pumps used at that time were sufficient. In the Swansea mine a steam pump was installed in the 700-foot level, and the water level, which was originally met at 650 feet below the surface was lowered to the 940-foot level.

In a shaft on the Iron Duke mine, 370 feet deep, the water level is 100 feet below the surface. The flow on the 350-foot level is said to have been 4,000 gallons a day.

At the Gemini mine, in the 300-foot winze from the 1,650-foot level, the water was held at 300 feet below water level by electric pumps lifting 300 gallons a minute. After the pumps were disabled the water rose to its former level. When this mine was studied by the writer 20,000 gallons a day of seepage water from the mine was being dumped into this winze without affecting the level of the water. Along the Gem or westerly channel the workings are wet for 300 feet above the water level. At other mines there is little dripping water above the permanent water level.

In the Centennial Eureka, along the same zone, the water level was found at an elevation of 4,851 feet, 2,036 feet below the collar. Large pumps were installed on level 20, or at an altitude of 4,671 feet. Much water was encountered in a drift from level 20 that was

bulkheaded some distance from the shaft. In 1911 about 1,000 gallons a minute was pumped to the tunnel level, and the water was used to irrigate a small ranch near the mouth of Eureka Gulch. After 1912 pumping was discontinued and the water rose to 75 feet below level 18, or 57 feet lower than the original level.

At no other mine have large pumping operations been attempted.

DRAINAGE OF THE DISTRICT.

Plans have recently (1915) been published for a drainage tunnel for the district, principally with the view of draining the monzonite territory, in which water is now encountered close to the surface and which is believed to contain a considerable amount of ore distributed in many veins. Such a tunnel would cut the present shafts above the water level in the limestone but of course would facilitate pumping by lessening the height to which the water must be raised. The plan is feasible and commendable. The tunnel would have to start from Goshen Valley, 5 miles away, at an altitude of 5,000 feet. On a grade of 1:300, or 88 feet in 5 miles, the tunnel would reach the bottom of Iron Blossom No. 1 shaft at an altitude of about 5,075 feet, or 2,200 feet below the collar, and the Sunbeam shaft at an altitude of about 5,090 feet, or 1,440 feet below the collar.

MINERALIZATION.

GENERAL FEATURES.

In the preceding statements it is shown that the ore deposits of Tintic follow a system of fractures which begin in the monzonite, monzonite porphyry, and Swansea rhyolite porphyry near Silver City and continue with a general northeasterly trend toward the contact of the igneous and sedimentary rocks; north of the contact, in the sedimentary rocks, the deposits follow a more complicated fracture system with predominant northerly trend, but the mineralization is not so general as in the igneous rocks, being confined to four ore zones, in part connected, known as the Gemini, Mammoth, Godiva, and Iron Blossom zones.

The deposits may conveniently be considered in two divisions—those in igneous rocks and those in sedimentary rocks. To these should be added a small class of oxidized iron ores that have been formed at or near the contact between the sedimentary and the igneous rocks.

The two main divisions are characterized by the same general mineral composition. The principal gangue minerals are quartz and barite, the quartz usually in the form of fine-grained jasperoid. The principal ore minerals are galena and enargite. Zinc blende and pyrite are invariably present, though commonly in small quantities. There is also an unknown bismuth mineral which has been oxidized to oxide, carbonate, or arsenate of bismuth. Tetrahedrite, famatinite, and chalcopyrite occur in subordinate amounts.

The metals, arranged in their order of value, are silver, lead, copper, gold, zinc, bismuth, arsenic, and antimony, but the last three are of small economic importance. Nevertheless some of the bismuth is doubtless recovered in the treatment of the lead bullion; some arsenic is recovered as flue dust and a little of the antimony ultimately finds its way into hard lead recovered as a by-product in desilverization.

DEPOSITS IN IGNEOUS ROCKS.

The deposits in the igneous rocks have been worked only to shallow depths, operations generally ceasing at the water level. Only one mine, the Swansea, has reached a notable depth, its shaft extending 940 feet below the collar and 290 feet below water level.

The primary ore minerals of these deposits are, in the order of abundance, pyrite, galena, and enargite; the gangue minerals are normal vein quartz, in places well crystallized, and barite. The valuable metals are silver, lead, copper, and in some places gold. No bismuth minerals have been observed. The principal vein filling consists of pyrite. The silver content is highest, as a rule, in the galena and enargite, but some of the pyrite in the Swansea veins is said to contain enough silver to make ore.

The width of the veins is rarely more than a few feet.

Both filling and replacement have played parts in the genesis of the deposits, and the ore in some places grades into the altered country rock.

The country rock is extensively altered to pyrite and sericite, with residuary quartz. Some microscopic alunite is also found in the veins and locally in the silicified monzonite

porphyry. In both occurrences it has the appearance of being primary.

In the Swansea mine the vein follows a zone of linked fissures, whose average width is 3 feet, and the vein minerals are commonly arranged in bands separated by sericitic and pyritic country rock. At one place, for instance, a section showed 18 inches of pyrite and galena, 18 inches of galena and quartz, 30 inches of pyrite and quartz, 65 inches of galena, 3 inches of pyrite, and finally 3 inches of galena. No enargite or barite is found in this mine, and the ore contains but little gold. An average sample of the ore would give 0.03 ounce of gold and 30.7 ounces of silver to the ton, 0.26 per cent of copper, 12 per cent of lead, 31.0 per cent of iron, 0.9 per cent of zinc, and 19 per cent of silica.

Little is known in detail of the processes of oxidation in the ore of these deposits, for few of them have been worked in the last 20 years. Limonite and lead carbonate were the principal minerals, and much of the oxidized ore was rich in silver. If the district is drained by a tunnel many of these veins may again be worked.

DEPOSITS IN SEDIMENTARY ROCKS.

In the sedimentary rocks, which consist mainly of dolomite, limestone, or shaly limestone, the mineralization assumes a different type. The extensive impregnation with pyrite and the sericitization shown in the deposits in igneous rocks do not occur except in such dikes as may have broken into the strata. Instead the ore zones are marked by strong silicification, the silica taking the form of jasperoid, which, with some barite, replaces limestone or dolomite. Some of the jasperoid resembles a fine-grained quartzite; in the northern and eastern part of the district it assumes a cherty or flinty appearance. The color of the jasperoid is usually gray or bluish gray. Its width is from a few feet to 100, or, in a few places, 200 feet.

In the ore shoots the jasperoid contains finely disseminated galena, with some zinc blende and pyrite and in places larger accumulations of the same ores accompanied by a quartz of lighter color and more distinctly crystallized; barite is also associated with this ore. Other ore shoots contain much enargite, with some pyrite and chalcopyrite, or famatinite or tetrahedrite. Such copper shoots usually contain a little lead, especially along the margins; there is much barite, and the jasperoid is less conspicuous. When oxidized these shoots contain much limonite. The lead shoots and the copper shoots usually occur separately, but mixed shoots are found, for instance, in the Eureka Hill mine.

OXIDATION.

The Tintic district is remarkable for an unusually low water level and a corresponding great depth of oxidation. The water in the sedimentary rocks stands from 1,650 to 2,400 feet below the surface, according to the altitude of the shaft collar, and broadly speaking, is found about 300 feet above the level of Utah Lake, or at an altitude of 4,800 feet. Explorations in ore below the water level had been undertaken only in the Gemini mine.

The oxidation has thus penetrated to unusual depths. On level 21 in the Mammoth mine, for instance, at a depth of 2,300 feet, the oxidation is strongly marked. The ore is honeycombed and limonitic and has the appearance of a surface gossan. In no mine, however, is the oxidation complete. Residual masses of enargite, pyrite, and galena may be found at all levels as well as at the surface, though both galena and enargite are more abundant in the lower levels.

The oxy-salts formed in lead and zinc mines consist of anglesite, cerusite, plumbojarosite, smithsonite, calamine, and hydrozincite; the copper mines yield a long series of copper arsenates, malachite, and azurite, more rarely cuprite, and native copper. The silver takes the form of cerargyrite and native silver, and some rich oxidized ores show native gold.

The oxidation is generally accompanied by solution of quartz; the barite is very resistant. In places, however, a little quartz was deposited contemporaneously with the oxidation.

The Tintic ores are generally soft crumbling masses of cellular and honeycombed appearance, more or less stained by limonite, and oxidized copper minerals and containing in places residual galena and enargite. Too little deep work has been done to reveal much about oxidation below the water level. A rich sulphide ore 250 feet below water level in the Gemini mine shows some oxidation with the development of small cerusite crystals, through

which wires of native silver pass, so that oxidation certainly continues to some extent to a considerable distance below water level.

In a large part of the upper zone not enough oxygen was available for complete oxidation. In such places much galena remains, some of the enargite has suffered a partial oxidation, and secondary chalcocite and covellite have been contemporaneously developed high above water level. Proustite and argentite, found occasionally in some mines, were probably deposited during the general process of oxidation wherever the supply of oxygen was scant.

No positive conclusions have been reached as to the existence of sulphide enrichment below or at water level. A very peculiar rich ore from the Gemini mine, described on page 177, contains galena, pearceite, zinc blende, and marcasite. It occurs from 250 feet above to 250 feet below water level and is certainly later than the first mineralization.

Oxidation is of so great importance in connection with the Tintic mines that a separate chapter is devoted to it (pp. 160–171).

ZONES OF DEPOSITION IN A HORIZONTAL DIRECTION.

The deposits of the Tintic district show in a marked degree a variation of mineral association apparently dependent upon the intrusive monzonite. Four zones of distinct character may be recognized.

1. In the monzonite quartz occurs in well-developed crystals with much pyrite and some barite, galena, enargite, zinc blende, and chalcopyrite.

2. In the sedimentary rocks to a distance of 1 to 1½ miles north of the contact with the monzonite the gangue consists of some fine-grained replacement quartz, with a few small druses of well-crystallized quartz and much barite. The ores contain much enargite and in places a little pyrite, also tetrahedrite and famatinite. There are a few lead shoots, and the copper shoots contain a little lead. The ores also carry gold, averaging in the better grade of ore $10 to $12 a ton, and some silver probably averaging 20 ounces to the ton.

3. Farther north, in the same vein zones, the sedimentary rocks contain principally galena, with a little zinc blende and pyrite. The silver content is higher than farther south, the average of the ores being perhaps 30 to 40 ounces to the ton. There is practically no gold. The gangue minerals consist of predominant quartz in the form of an extremely fine-grained cherty material replacing limestone or dolomite, but there is also a moderate amount of barite. The quartz crystals in the drusy cavities that occur here and there are rarely more than 1 millimeter in length. This zone continues, so far as known, for 1 or 1½ miles north of the end of the copper zone.

4. Farther north and east, beyond the area containing the lead-silver shoots, the mineralization becomes more feeble. The gangue minerals consist of calcite, dolomite, and a little quartz; the ore minerals comprise galena and zinc blende; and silver is present only to the extent of a few ounces to the ton.

Gold and copper seem thus to occur on the whole near the monzonite; lead and silver and zinc mainly farther away. This arrangement may correspond to deposition in successively cooler zones and a gradual spreading of the ore-forming solutions toward the north until they became so mingled with surface waters that their solvent power declined.

ZONES OF DEPOSITION IN A VERTICAL DIRECTION.

Far less marked is the variation in the composition of the ore with variations in depth in the individual mines. The separation of the ore into lead shoots and zinc shoots is dependent upon processes of oxidation. In any one mine within the copper zone lead and copper shoots may occur in close proximity, but there is no definite change with increase in depth. In some mines which in the upper levels carried only lead copper began to appear lower down.

GENESIS OF THE DEPOSITS.

The mode of origin of the deposits is taken up in more detail in another place (pp. 182–184). It is well to state here, however, that there can be no reasonable doubt that all the precious metal deposits of the district were formed at one time, and that the genesis of the ores in monzonite is the same as that of the ores in sedimentary rocks. The similarity of the unusual type of mineralization in both classes of rocks, the general continuity in strike, and finally the actual tracing of one of the normal veins across the monzonite-limestone contact suffice to prove this assertion. The deposits

were probably formed by hot waters, charged with igneous emanations, rising on fissures in the monzonite after its consolidation. These waters penetrated the sedimentary rocks north of the monzonite and, spreading, gradually became cold and lost their power of mineralization.

The ore deposits were formed immediately after the end of the intrusive activity in the interior part of a cooling volcanic mass and at a depth of not more than a few thousand feet below its surface.

ORE BODIES.

DEPOSITS IN IGNEOUS ROCKS.

Concerning the form of the veins in the igneous rocks not much can be said, for little is known of the occurrences in the old workings. The ore bodies are tabular, varying in thickness from that of a seam to 20 feet. Tower and Smith [1] say that the average width is 2 feet, and that the limits of ore and altered country rock are everywhere well defined, though the two are rarely separated by clay seams. The most continuous body is that of the Sunbeam vein, which is 2,000 feet long. The pay shoots are really thin lenticular bodies of galena ore. In the Swansea mine, where the workings have been extended below water level, the vein ranges from 1 to 10 feet in width. About half of this vein is composed of shipping ore.

In the Swansea mine there are two main shoots and several small ones. The northern shoot was 600 feet long on the surface and reached a maximum depth of 130 feet. The southern shoot has been stoped from a point near the surface to a depth of 800 feet and through a maximum horizontal distance of 900 feet. Its shape on the plane of the vein is that of a T with its stem pitching 35° N.

There seems to be no reason why some of the other veins in the monzonite could not be profitably worked below the water level.

DEPOSITS IN SEDIMENTARY ROCKS.

GENERAL RELATIONS AND FORM.

The sedimentary rocks are much more susceptible to replacement than the igneous rocks and consequently the ore bodies within them are much more irregular and complicated than the veins in the igneous rocks. From a narrow fissure the ore extends irregularly on both sides and is rarely limited by a regular wall. If the ore stops at a fissure at one point it may extend beyond it at some other point. The change from ore to barren vein material is usually indistinct, but the jasperoid, which is the principal gangue material, is as a rule sharply separated from the unaltered limestone or dolomite. At many places shoots have been mined twice—the richest ore was first extracted and later on, at a more favorable time, the second-class ore was mined.

As stated above (p. 122), the ore in many deposits follows northerly fissures that are nearly vertical, but the ore may follow any fissure and have any dip; or it may follow the bedding planes of the rock, whatever dip these may have.

The ore bodies are called chambers, columns, chimneys, pipes, pockets, or pods; the last is an especially apt term and is applicable to many deposits. An ore body that follows gently inclined beds is called a flat or a blanket. Many of the pipes are extremely irregular, especially along the Gem channel in the Gemini mine; this channel trends N. 15° E., and the ore has a maximum width of 30 feet.

One of the largest ore shoots, that of the Mammoth, has been followed from the surface along its steep pitch to a depth of 2,000 feet. This shoot was about 200 feet in length and 30 to 150 feet in width.

The longest shoot known is the flat body of the Iron Blossom, Sioux, Colorado, and Beck Tunnel mines, which has been mined almost continuously for nearly 8,000 feet. For the first 5,000 feet it strictly follows the intersection of a fissure with a certain bed of flat-lying limestone and for the remaining 3,000 feet it is a replacement deposit along the same fissure but of more veinlike form. The greatest width is about 150 feet, but for the most part it is considerably narrower.

Tower and Smith remark that few of the ore bodies split or send out offshoots; where an ore body passes from one fissure to another, the first fissure is usually barren beyond the point of departure. This is illustrated by several ore bodies in the Gemini mine, which show a U shape in horizontal projection, caused by the ore leaving a northerly fissure for a cross

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 712.

break and then taking a parallel fissure. (See Pl. XXXII, p. 186.)

All these facts illustrate the difficulties attending the discovery and mining of ore bodies in the Tintic district. The cost of exploration is high, and successful mining requires an intimate knowledge of the structure of the rocks.

OUTCROPS.

The large ore bodies in the sedimentary area crop out in few places. In fact, as pointed out elsewhere, this part of the district presents to the observer of the surface very few indications of mineralization.

In the monzonite the veins crop out at many places at altitudes ranging from 6,100 to 6,800 feet.

In the southern part of the sedimentary area, where the deposits still preserve their vein character, outcrops are abundant, though few large ore bodies have been found. These veins crop out on the North Star, Red Rose, Victor, and Carisa properties at altitudes of 7,000 to 7,600 feet, also along the Governor vein at about 7,000 feet.

Farther north along the same vein zones the outcrops are scarce and the main ore bodies lie a few hundred feet below the surface, at altitudes of 7,000 to 7,300 feet. In the May Day mine the ore reached almost to the surface, at an altitude of about 6,900 feet. Along the Iron Blossom ore zone there are no outcrops north of the Iron Blossom shaft No. 1, and the main ore bodies for 1¼ miles lie 100 to 300 feet below the surface, at altitudes of 6,800 to 6,900 feet.

Along the Mammoth ore zone there are prominent outcrops at the Mammoth mine, at an altitude of 7,000 feet. Farther north the outcrops are scarce, but one ore body reaches the surface in the old Eagle and Blue Bell workings at 6,950 feet. North of this point the ore bodies lie far below the surface.

No outcrops are visible above the Grand Central ore shoots, but near the Centennial shaft outcrops of the New Year channel are found at an altitude of 6,900 feet and continue unbroken for 1,200 feet almost to the Eureka Hill mine, at 6,500 feet. In the Gemini mine no ore was found above the second level, at about 6,300 feet, but a mineralized outcrop of the Tank channel was observed just north of the shaft.

The Tintic ore deposits thus show outcrops in all except in the most northerly parts of the area, though the outcrops are rarely continuous or prominent. These outcrops range in altitude from 6,100 to 7,600 feet; the former figure practically represents the western base of the range, while its summit reaches 8,100 feet.

It is thus clear that the ore deposits are not limited to any one horizon. These relations have been discussed in some detail on account of a statement by Jenney [1] to the effect that "in the limestone area of Tintic * * * surface outcrops occur but seldom and are mainly confined to points of relatively low elevation where the veins cross some basin or ravine. Nowhere does a considerable body of ore outcrop on the tops or high up on the slopes of the hills." It will be readily seen that this statement is not supported by the facts.

COUNTRY ROCK.

Of the several rocks in the sedimentary series certain relatively pure dolomites and limestones appear to be the most favorable formations for ore deposition. No ore deposits, except a few small quartz veins of no economic importance, occur in the basal quartzite or the overlying shale of the Tintic district, nor in the arenaceous and shaly limestone of the Humbug formation. The deposits of lead ore at or close to the quartzite-shale contact in the Tintic Standard mine, in the East Tintic district, owe their presence more to the impounding influence of the shale than to the favorable character of either rock. Few ore bodies are contained in the limestones of Middle Cambrian age (Teutonic, Dagmar, and Herkimer limestones and Bluebird and Cole Canyon dolomites). The ores of the Bullion Beck, Eureka Hill, Centennial Eureka, and Gold Chain mines occur in the Opex dolomite and Ajax limestone, but these formations contain few deposits elsewhere. The shaly Opohonga limestone contains some ore in the Grand Central mine, but is otherwise generally unfavorable.

The Bluebell dolomite carries many of the great deposits, such as the Gemini, Chief, Eagle and Blue Bell, Victoria, Grand Central, and Mammoth. The Gardner dolomite contains some of the ore bodies of the southern

[1] Jenney, W. P., The mineral crest * * * in certain mining districts of the Great Salt Lake Basin: Am. Inst. Min. Eng. Trans., vol. 33, p. 46, 1903.

part of the Iron Blossom vein but is generally unproductive.

In the upper part of the Pine Canyon limestone, 200 or 300 feet below the top of the formation, lie some thick beds of coarse granular limestone, and these beds, north of the Sioux-Ajax fault, contained the rich ore bodies of the Iron Blossom, Sioux, Colorado, and Beck Tunnel mines. The Godiva and May Day mines are also in the Pine Canyon formation. This ore-bearing limestone is very pure. One analysis given by Jenney [1] shows 98.75 per cent calcium carbonate, trace of magnesia, 0.40 per cent oxides of iron and alumina, 0.20 per cent silica, and 0.65 per cent organic matter and loss. When broken this limestone gives a fetid odor, but this is also observed in some of the dolomites.

The following analyses are given by Tower and Smith: [2]

Analyses of carbonate rocks from the Tintic district.

	1	2	3	4
SiO_2	8.77	4.33	0.57	17.19
Fe_2O_3	.49	.63	.90	.48
CaO	27.22	52.34	55.22	43.78
MgO	18.53	.60	.41	.91
CO_2[a]	41.77	41.78	43.84	35.40
	96.78	99.68	100.94	97.76

[a] Calculated.

1. Cole Canyon dolomite.
2. Upper part of Ajax limestone. The Ajax is for the most part more magnesian than this analysis would indicate.
3. Upper part of Pine Canyon limestone.
4. Sandy limestone in Humbug formation.

The Bluebell dolomite is fine grained and many of its beds are colored dark by organic matter. An analysis averaged from six [3] gave the following results: Calcium carbonate, 55.38 per cent; magnesium carbonate, 42.84 per cent; silica, 0.65 per cent; and undetermined and loss, 1.13 per cent.

In the Bullion Beck, Eureka Hill, and Centennial mines the rocks are in part magnesian and much of the ore is in the Opex dolomite. The dolomite appears to be relatively impure. An average of seven analyses of specimens from "the vicinity of the Bullion Beck mine," [4] gave calcium carbonate, 48.76 per cent; magnesium carbonate, 35.43 per cent; ferrous carbonate, 2.61 per cent; silica, 9.67 per cent; alumina, 3 per cent; and organic matter and loss, 0.53 per cent.

The above statements make it clear that the ores developed more readily in the purer dolomites and limestones; that in certain rocks a granular structure was favorable; that some dolomites in which ore formed averaged 10 per cent silica but that more silica and alumina was probably unfavorable for ore deposition; and that while organic matter is universally present it does not seem to have had a determining influence on the course of ore deposition.

ORE BODIES OF THE GEMINI ZONE.

In the Gemini mine the ore bodies occur as podlike masses or small pipes along four almost vertical fracture zones which strike a little east of north and practically coincide with the strike of the dolomitic beds. Plate XXXI and figure 25 (p. 188) show them in plan and cross section. A longitudinal vertical projection would show that many of these bodies are extremely irregular and in places joined by pipelike connections. This feature is illustrated in figure 26 (p. 189), which shows the occurrence of the deepest ore body in the Gem channel.

In the plan (Pl. XXXI) the influence of cross fractures is seen to be marked in several places, where the ores follow these fractures and give rise to U-shaped bodies. Few of the ore bodies are large. The central parts of the bodies are usually the richer and are surrounded by poorer jasperoid.

A tendency to northward pitch is seen in many of the ore bodies. In the Gem channel no ores occur above level 12, but in the Bullion Beck mine the ore of the same channel lies considerably higher. The most northerly workings in the Ridge and Valley property lie on levels 14 and 16. The largest bodies are found in the Tank and Red Bird channels on levels 600 and 700. The peculiar ore of the bodies in the Gem channel is described in more detail on page 177.

The ore-bearing fissures continue southward into the Bullion Beck mine where they form a similar series of podlike bodies (fig. 26, p. 189). The Gem channel and a more easterly fracture zone, called the Eureka channel, are the most

[1] Jenney, W. P., The chemistry of ore deposition: Am. Inst. Min. Eng. Trans., vol. 33, p. 478, 1903.
[2] Tower, G. W., jr., and Smith, G. O., op. cit., p. 623.
[3] Idem, p. 477.
[4] Idem, p. 475.

productive and locally follow a south-southeast swing in the stratification. South of the shaft they approach within 250 feet of each other, and the ore bodies of the two coalesce to a large pod, which in places is over 100 feet in diameter. In part this pod is in the Eureka Hill mine, in which the largest masses of ore were mined on levels 1 to 6, while explorations of lower levels did not disclose much of value. (See figs. 28 and 29, pp. 195, 196.) In the southern part of the Eureka Hill mine the two channels are again distinct, turn more nearly north, and form the large and continuous bodies of the Silver Gem stopes, reaching from level 9 of the Eureka Hill up to level 4. This Silver Gem ore body is 60 feet in maximum width and is continuous on some levels for 700 feet. Any longitudinal section of the ore bodies along the channels is likely to be very irregular; an ore body may follow a given level for a long distance, to connect in some irregular manner with the ore on a lower level.

In the southern part of the Eureka Hill mine the copper ores begin to appear; in some places copper stopes adjoin those of lead ores, and some stopes carry mixed lead and copper ores. Gold has begun to increase in the ore; in fact, this metal appears first in the Bullion Beck mine in appreciable quantities.

In the Centennial Eureka, the most productive mine in the district, the ore begins on the north side along three lines, known as the Gem, Eureka, and New Years channels, all continuous from the north. Lead ores are present in places, but gold and copper are the principal metals. In this northern part of the mine the channels are comprised within a width of 300 feet from east to west and the ores form horizontal shoots as much as 20 or 30 feet wide, much more veinlike in appearance than the pods of the more northerly mines. None of these ores have been found to extend much below level 11; the New Years channel crops out at the surface. The Gem channel, which is the most persistent of the several lines, continues southward to a great easterly cross break, which is accompanied by a second parallel break 1,000 feet farther south. The whole character of the ore shoots changes at these cross fractures.

The main ore bodies of the Centennial mine consist of three great "columns," two of which in general follow these cross breaks, partly in the footwall and partly in the hanging wall. (See fig. 30, p. 199.)

The first of these, which may be called the California column, connects on level 6 with the Gem channel. It extends obliquely on the first cross break, pitching about 50° SE. from level 6 to level 17, a distance of 2,500 feet, and having an irregularly rounded cross section measuring as much as 100 by 100 feet. From level 14 it begins to flatten and leaves the first cross break. In the lowest stopes, called the South Dakota, the ore lies on top of a flat intrusion of Swansea rhyolite porphyry 20 to 50 feet thick. This flattening also has some connection with the attitude of the strata, which at this depth of about 2,000 feet have decreased their dip, and this change in attitude is accompanied by much brecciation of the limestone.

As the California column is related to the first cross break, so the other two columns are dependent upon the second cross break or, more specifically, upon the intersection of this break with a strong northerly fracture, called the East Limit, the pitch of the ore coinciding roughly with the dip of 70° S. of this second cross break.

Just as the Gem "channel" leads into the California column, so there are two northerly fractures 500 and 1,000 feet southeast of the shaft which lead into the second cross break. The first of these lies along the so-called Big Platform stopes on levels 2 and 3, which at first are narrow and then widen to 70 feet in the Montana stopes. On the south side of the Montana stopes the second cross break is encountered, and the narrow ore is continued on this plane into the big Oregon and Maine stopes, on levels 4 and 5. From this point a column of ore descends steeply to level 12 and probably connects below this with the North Dakota flat stopes on level 17.

The second of the easterly "channels" begins in relatively narrow stopes on levels 5 and 6, meets the second cross break, and descends as a strong column or pipe from 30 to 125 feet in diameter to level 14, from which ore connection is established with the South Dakota flat stopes on level 17, which thus forms the converging point for the two greatest ore columns of the mine. The column just described is determined by the intersection of the second cross break and the East Limit.

In depth the ore begins to spread laterally, becoming more or less independent of both these structural features.

Ore has thus far not been found below level 18, but it extends irregularly eastward and doubtless connects in smaller bodies with the lower ore zone of the Grand Central mine.

In the Gemini mine the ore occurs within a vertical range of about 1,300 feet, reaching from a lowest altitude of 4,500 feet at the north end, where the workings are still in ore, up to an altitude of 5,800 feet. In the Bullion Beck and Eureka Hill mines the principal ore was found between altitudes of 5,400 and 6,300 feet. In the Centennial Eureka mine the ore practically reached the surface at 6,900 feet. On the north side it descended to 5,800 feet, and at the south end, where this ore zone ceases, the lowest ore was found at 4,800 feet.

In very general terms these facts may be expressed by saying that the upper surface of the ore so far as shown rises in a broad curve from an altitude of 4,800 feet north of the Gemini shaft to 6,100 feet at the shaft, to 6,400 feet at Eureka Hill, and to 6,900 feet at the Centennial shaft, south of which the ore drops rapidly along the dip of the two great cross breaks. The lower limit of the ore zone, so far as known, lies below 4,500 feet north of the Gemini mine, at 5,200 feet near the shaft, at 5,600 feet in the Eureka Hill mine, at 5,700 feet at the Centennial shaft, and at 4,800 feet in the southern part of the Centennial property.

ORE BODIES OF THE MAMMOTH ZONE.

The Chief Consolidated mine contains the most northerly bodies of the Mammoth ore zone. The limestones are covered by about 300 feet of rhyolite and detrital material, so that no outcrops are visible. Two principal systems of ore bodies are worked, the first centering about 700 feet northeast of the shaft and consisting of two parallel bodies 100 or 150 feet apart. The ore bodies which are as much as 30 or 40 feet wide extend in a northerly direction along indistinct fissures for at least 500 feet. The strike of the limestone is N. 10° W. and the dip about 75° E., but in the 1,600 and 1,800 foot levels flatter dips were observed. In places the ore bodies are surrounded and separated by large masses of jasperoid that constitute ore of low grade. In form they seem to be a succession of almost vertical podlike or irregular masses much like those of the Gemini and Eureka Hill mines. In this northerly system galena and siliceous silver ores have been extracted from the 1,300, 1,400, 1,600, and 1,800 foot levels.

The southern ore bodies are separated from those just described by 1,200 feet of barren ground and connect with the northerly ore bodies of the Blue Bell mine. They extend horizontally for 500 feet and vertically from the 750-foot to the 1,400-foot level. The ores, which are siliceous, carry mainly galena, in part oxidized, with 30 or 40 ounces of silver to the ton, and in the southern part of the mine an appreciable quantity of gold begins to appear in the ore. Copper is present in small quantities.

There is, then, in this succession of ore bodies a distinct northward pitch, just as in those of the Gemini mine.

In the Eagle and Blue Bell mine the strike of the beds is again a little west of north and the dip 65°–70° E., slightly flatter than in the Chief. The ore bodies are mainly determined by the intersection of northerly fractures with certain strata susceptible of replacement, but in part they also follow northeasterly cross fractures. The ores mined are lead ores, oxidized in part, very siliceous, and in places carrying some gold. The ores worked in past years were in the southern part of the property and occurred in a pipelike shoot that was followed from the surface to a depth of 500 feet. The later developments are in the northern part of the property and are in general related to the intersection of an easterly cross break with a northerly fissure. The ore forms an irregular body beginning about 700 feet below the surface and continuing to the 1,600-foot level, the lowest reached in 1914. The shoot has been followed south for 500 feet and is from 20 to 70 feet wide.

A new and rich lead shoot extending from the 1,450-foot level down to the deepest (1,700-foot) level lies a few hundred feet southwest of the one just described. Its structural features have not been fully worked out, but on the 1,600-foot level it is 140 feet long and as much as 20 feet wide.

The shoots in the Eagle and Blue Bell mine thus show in their successive position a decided northward pitch, similar to that observed in the Gemini and Chief mines, but

there are also many smaller offsets pitching south and probably due to southward-dipping cross breaks.

The ore bodies of the Victoria mine do not connect directly with those of the Eagle and Blue Bell but lie about 500 feet farther east. They extend over a distance of about 1,400 feet from north to south and connect directly with the stopes of the Grand Central mine on the south. They do not crop out. The ores are highly siliceous and carry gold and silver with bunches of copper ore and more rarely lead ore.

The Victoria ores form a series of disconnected bodies of silicified dolomite, 30 feet in maximum width and very irregular, yet clearly arranged in line as a series of northward-pitching masses of ore. On the Grand Central boundary they are found on the 600 and 700 foot levels as roughly horizontal, northward-trending bodies, but a few hundred feet beyond the boundary the trend swings to N. 20° E. and the decided northward pitch begins, so that 400 feet north of the shaft the jasperoid ore is found at the 1,200-foot level and no ore lies above it, so far as known. In general the ore bodies trend N. 20° W., following the strike of the dolomite, but they show many local enlargements and offshoots along cross breaks. The dip of the beds is only 50°-65° NE., but the ore bodies as a whole show no marked tendency to pitch in this direction. The determining influence in the mineralization was evidently an obscure fracture zone trending northward, with repeated offsets toward the west. What causes the northerly pitch is not definitely known. One peculiar occurrence in this mine was a nearly spherical mass of jasperoid, about 20 by 30 feet, on the 1,100-foot level, containing 1 to 2 ounces of gold to the ton and a little silver but no lead or copper.

In the Grand Central mine the principal ore zone extends in the main horizontally between the 500 and 900 foot levels (fig. 31, p. 213) for a distance of 2,500 feet. On the north it connects with the ore bodies of the Victoria; on the south it connects with those of the Mammoth, and in that vicinity the ore turns decidedly upward in the Silveropolis shoot and reaches the surface at the Cunningham stope of the Mammoth mine. This principal ore zone intersects bedding and dip and in general follows prominent northerly fractures intersected by other fractures trending N. 30° E. The Silveropolis shoot (fig. 32, p. 216) forms a pipe that pitches 70° NW. across the stratification, probably following the intersection of two fracture planes. This shoot crosses into Grand Central ground and continues, flattening somewhat, to levels 8 and 9. There it turns north, following a steep fissure, and is practically continuous horizontally to the Victoria boundary. In the Butterfly stope this ore body reaches its greatest development at the intersection of the northerly fracture with a vertical north-northeasterly fracture and extends from level 4 to level 11; its greatest width here is 50 to 70 feet. The deeper levels contain ore mainly west of this principal zone, at first along the west fissure, which strikes north-northeasterly and dips 73° NW. On the deepest levels (20 and 22) this ore body flattens, connecting with minor bodies which extend almost to the Centennial Eureka ore bodies and which in part follow the stratification, in part the marked north-northeasterly fissures in or near the Emerald-Grand Central fault zone west of the shaft. It is probable that the whole Gemini ore zone received its contents from solutions working northward from the vicinity of the Mammoth. Throughout the mine the ore bodies have a tendency to a northerly pitch, caused by their development along the intersection of north-northeasterly fissures that dip north-northwesterly with northerly fractures that stand vertical.

The ores of the Grand Central mine carry mainly copper, gold, and silver; lead is present at many places.

In the Mammoth mine several ore bodies have been worked, most of them within 1,200 feet north and northeast of the shaft. All of them cross the bedding and most of them are determined by the intersection of two or more fissures striking north, north-northeast, and northeast. The largest body is called the Apex shoot. It crops out near the shaft and, in the form of a large chimney-shaped mass, goes down almost vertically and attains a greatest width of 100 feet on levels 15 and 16. The larger diameter trends N. 15° E. and the shoot continues to level 21, where, however, it becomes of lower grade. (See Pl. XXXIII, p. 214.) The shoot is evidently determined by the intersection of systems of fractures trending

from north to east. At the surface were found copper ores rich in gold; at depths of 1,500 feet a large lead shoot is recognized, adjoined by a gold shoot and, lower down, by another gold shoot that yielded much native gold. Silicified rock containing some gold and silver extends on the north-northeasterly fissures far beyond the boundaries of the ore bodies. A rich copper shoot was found on the Welding claim northeast of the shaft on levels 7 and 8; this appears to follow a N. 30° E. fissure and is in places 30 feet wide.

South of the Mammoth mine lie the Ajax, Gold Chain, and Opohonga ore bodies. The Ajax is a chimney of notable dimensions continuing from the surface down to the 1,000-foot level and determined by a system of northerly and north-northeasterly fractures. In the Gold Chain and Opohonga the ores form chimneys extending along the short north-northeasterly fissures on levels 3 to 10 of the Ajax workings. Copper, gold, and silver are the principal metals. The Ajax in particular has produced a large amount of gold. No direct extension of this zone is found toward the south, but a little west of the Ajax shaft is the Hungarian vein, which continues into the Lower Mammoth property, here accompanied by the West vein, 150 feet distant. (See fig. 33, p. 220.) In contrast to the deposits described above these veins occupy distinct and easily traceable fissures which intersect strike and dip and which are closely followed by the ore shoots. In other words, the ores do not spread on bedding and cross fissures but closely follow the path of the trunk fracture. The type is thus that of normal replacement veins. Both veins can be traced for 700 feet south of the shaft and dip very steeply to the west. The ores in the Lower Mammoth contain principally lead and silver with some zinc.

One principal ore shoot in the form of a flattening column has been found on the Hungarian vein, and two similar shoots on the west vein (fig. 33, p. 220). The lower shoot between levels 14 and 18 is of particular interest, for it extends along the contact of crystalline limestone and intrusive monzonite and the ore continues across the contact into the monzonite (fig. 34, p. 221). In the limestone the vein contained principally partly oxidized lead-silver ore and the stopes are 15 to 25 feet wide. At the contact on level 17 the vein narrows, but was followed into the monzonite for 50 feet—as far as the drift was accessible. The vein is here 4 to 6 feet wide and contained several stringers of heavy sulphide ore consisting mainly of pyrite, zinc blende, enargite, and tetrahedrite, with a very little galena. There is thus a marked change in the contents of the vein at the contact. The ore from the monzonite that was shipped contained 14 per cent of copper.

These veins are not traceable across the contact on the surface, but in the monzonite and in a general continuation of the Mammoth ore zone a considerable number of linked veins extend in a south-southwesterly direction toward the Cleveland and Iron Duke claims. The outcrops of these veins have been traced on Plate III (in pocket).

The practical continuity of the Mammoth ore zone from the vicinity of Silver City to the Chief Consolidated mine is beyond doubt.

The altitude of the ore bodies above sea level may be briefly summarized. In the monzonite the ore crops out at 6,200 to 6,800 feet. In the Lower Mammoth it ranges from 4,900 to 6,400 feet but does not crop out. In the Ajax the ore ranges from 6,000 to 7,000 feet and reaches the surface. A much wider interval has been found in the Mammoth, in which the ore lies between 4,700 and 7,000 feet. North of the Mammoth the ore nowhere reaches the surface but shows a marked tendency to follow a higher horizon of about 6,400 feet, though locally it pitches on other fissures to connect with the Centennial Eureka ores at the low altitude of 4,900 feet. From the Victoria through the Eagle and Blue Bell and Chief Consolidated mines the ore pitches northward in a series of detached bodies which reach the surface at only one point on the Eagle and Blue Bell, at 6,940 feet, and which descend to 4,700 feet in the Chief mine—about the same altitude as that of the lowest ore in the Mammoth.

These figures disclose no marked rule or regularity except for the northerly pitch from the Victoria mine, and this, as in the Gemini ore zone, is probably due to the premineral valley of Eureka Creek, which before the mineralization became filled with an impermeable blanket of clayey rhyolite, thus presenting an obstacle to the free movement of the ore-depositing solutions.

ORE BODIES OF THE GODIVA ZONE.

The Godiva zone is traceable from the Godiva mine almost due south to the monzonite contact, a distance of 2½ miles. Silver-lead ores predominate from the Godiva to the Northern Spy, a distance of 1½ miles; the ores from the southern part of the zone contain mainly copper, gold, and silver. Comparatively little work is being done in the mines of this zone.

The Godiva shaft is 1 mile east of Eureka, near the point where the limestone ridge rises boldly above the Packard rhyolite. The ore bodies follow northerly fractures on the steeply dipping limestone strata and show local deflections along cross fractures. On the upper levels the stopes extend almost continuously for 300 feet north and 500 feet south of the shaft and have a maximum width of 30 or 40 feet. Below the 300-foot level no large ore bodies have been found. A few irregular and small masses of ore were found in the limestone east of the main bodies. The ores are mainly galena, partly oxidized, carrying about 9 ounces of silver to the ton. Some oxidized zinc ores have been mined lately near the old stopes. It would probably be advisable to seek the continuation of the ore farther to the north and on the lower levels.

The ore bodies of the May Day mine lie 100 to 300 feet to the east. What is known as the Godiva or West channel (which, however, does not connect directly with the ore bodies in the Godiva mine) is continuous only for a few hundred feet, but 200 feet to the east of this the New channel or East channel extends for 1,400 feet as a series of irregular bodies, connecting with the Yankee workings on the south. The workings on the West channel evidently followed fractures extending north or north-northwest. One of the stopes is 100 feet long and as much as 40 feet wide. The bodies reached within 60 feet of the surface and at most 200 feet below the tunnel level, so that the vertical extent was about 400 feet. No extensive silicification accompanied the mineralization, and the ore consists of partly oxidized galena. Some ore bodies form irregular chimneys or pipes 4 to 6 per cent in diameter, containing almost pure galena.

Jenney[1] describes the occurrence of a remarkably large mass of pure galena in the Uncle Sam claim. The ore body was 50 feet long, 50 to 60 feet high, and 13 to 20 feet wide, and the ore averaged 75 per cent of lead and 50 ounces of silver to the ton; the galena directly adjoined the limestone wall rock.

The principal workings of the lower levels are on the East channel and are best seen on the 275 and 500 foot levels of the Uncle Sam shaft, where the ore bodies lie parallel to the bedding on the lower (east) side of a dike of rhyolite. Galena ore is also found on lower levels in the form of narrow pipes. In these bodies the galena ore generally adjoins the limestone directly without a marginal zone of extensive silicification, but large brecciated and silicified masses with a low tenor in silver are also found on the 800-foot level, though not in line with any known ore channel.

On the May Day claim along the East channel some bodies of galena ore have been worked in the upper levels, but they generally follow the stratification, which here dips 30°–40° E., and are in places underlain by secondary oxidized zinc ores. In some stopes a limonitic material directly underlying the lead has been found to be rich in gold, this doubtless also representing an enrichment.

From the May Day claim the galena ore continues southward along the same line but follows the stratification along a coarse-grained bed in the Pine Canyon limestone. These bodies, which have been worked almost continuously through the Yankee and old Humbug (now Uncle Sam) mines, evidently follow an obscure northerly fissure along its intersection with the favorable limestone bed, but in places the ore sends out branches several hundred feet eastward along cross fractures. The individual deposits are as much as several hundred feet in length but only a few feet thick and lie along the beds, which dip 10°–30° E. At one place on the Humbug claim a connection seems to be established along a cross fracture with the ore bodies of the Beck Tunnel mine. Locally the ore may occur in narrow pipes and chimneys. The silicification does not as a rule extend far beyond the ore. The ore bodies lie between altitudes of 7,000 and 7,300 feet, only a few hundred feet, at most, below the surface. No deep exploration has been undertaken. The silver content reaches 50 ounces to the ton, and the ore contains a little copper and gold.

[1] Jenney, W. P., The chemistry of ore deposition: Am. Inst. Min. Eng. Trans., vol. 33, p. 480, 1903.

South of the Humbug mine the ore, which has long been mined out, followed persistently the same horizon in the Pine Canyon limestone and was continuous for a distance of 5,000 feet from the Utah to the Northern Spy. Along this southward line, presumably representing a fracture, which, however, is obscure, the ore lay along the dip (say 40° E.) but was in places deflected along easterly cross fractures. The ore bodies were from 2 to 50 feet wide. The altitude of this nearly horizontal ore channel is about 7,300 feet. The ore is similar to that of the Yankee and Humbug mines. There are no wide zones of silicification.

South of the Northern Spy mine the ore zone crosses the Sioux-Ajax fault without marked deflection, turns south-southwest, and, entering the Bluebell formation, assumes a distinct vein form. In the Carisa mine valuable bodies of copper ore were mined from the surface vertically down to a depth of 700 feet; the shoot or pipe had a horizontal length of 500 feet and was at most 50 feet wide. At a depth of 800 feet this copper shoot entered the Victor mine, adjoining on the south. The ore was siliceous, containing quartz, barite, and enargite, with some gold and as much as 25 ounces of silver to the ton. No deeper exploration was undertaken.

South of the Carisa the ore zone appears as more or less continuous veins. In the Victor mine the end of the Carisa shoot was soon found and small bodies of arsenical copper ore were mined on the lower levels. No explorations were undertaken below the 800-foot level. The ore followed N. 35° E. and northerly fractures, and the vein, which is contained in contact-metamorphosed limestone without plain bedding, is from 6 inches to a few feet wide.

In the southerly continuation of the Victor property extends the North Star vein, which almost reaches the monzonite contact. This vein is contained in contact-metamorphic limestone and has been opened to the 600-foot level. The ore-bearing fissure has been traced for 1,500 feet on the surface and is almost vertical. The ore bodies follow north-northeasterly fissures with local offsets on easterly cross fractures. Their maximum width is 30 feet and usually appears at the intersection of several fissures. The stoped ore bodies do not seem to have extended far below the 300-foot level nor more than 500 feet on each side of the shaft. The ore contained copper, lead, silver, and gold, and gold occurred in unusually large amounts, forming two-thirds of the value of the ore. The four shoots known are said to dip west and pitch north; three of them were distinctly gold bearing, and the fourth carried mainly lead and silver.

The ore bodies of the Godiva zone extend for a distance of 2½ miles from north to south along a fissure which south of the Northern Spy mine turns to a south-southwesterly direction. From this turning point northward the ore occurs in linear bodies that extend in general horizontally, closely following a bed of course limestone in the Pine Canyon formation. Their width from east to west is comparatively small, and their thickness generally less than 10 feet. South of the turning point mentioned, which coincides with the Sioux-Ajax fault, the deposits assume the form of nearly vertical veins in crystalline limestone, but the ore bodies are still confined within a relatively small vertical interval. In this area copper ores with more or less gold and silver replace the lead ores of the northern part of the zone.

The most remarkable fact about this ore zone is the persistence of the ore bodies within a small vertical interval, for they are confined between altitudes of 6,500 and 7,500 feet and the lowest limit is reached at the north and south ends, in the Godiva and North Star mines. The greater part of the ore zone lies at altitudes of 7,000 to 7,300 feet. Deep exploration has been attempted in few places and generally with poor success. There is, however, a strong possibility that the ores may be found to continue north of the Godiva with a northward pitch, as in the Gemini and Mammoth ore zone. No development work has yet been done in this direction.

ORE BODIES OF THE IRON BLOSSOM ZONE.

The Iron Blossom ore zone is the most easterly of the main lines of ore bodies. It is also the most remarkable of the four zones and in many respects unique. The stopes are practically continuous for 7,000 feet in a horizontal direction, and the total length of the zone is 11,000 feet. (See Pls. XXXV and XXXVI, in pocket.) It differs from the other zones in containing a single main ore deposit that is continuous throughout the zone from

the contact of the limestone and monzonite porphyry on the south to the Beck Tunnel mine on the north. The northward continuation of the zone has been sought by deep development in the Yankee mine, but so far without success. It will be convenient to begin the description from the south end.

Briefly, the deposit begins as a well-defined but narrow vein and keeps this character, though becoming wider and more productive northward to a point a few hundred feet south of Iron Blossom No. 3 shaft, where it encounters the Sioux-Ajax fault. North of this fault the deposit forms a linear body extending for 7,000 feet in the general direction of the vein, approximately along the axis of the great Tintic syncline, and following certain beds of coarse gray limestone in the upper part of the Pine Canyon formation.

Silver-lead ores and quartzose silver-gold ores with a little lead predominate from the north end to Iron Blossom No. 1. South of this point copper ores begin to occur mixed with ores of the types just mentioned. A great deal of work has been done along this zone of late years, particularly in the Iron Blossom mines. Although the vein deposits at the south end have been known for a long time, the notable production began in the Beck Tunnel mine in 1905 and in the Iron Blossom in 1908.

The developments in the Dragon property have shown that the outcrop of a narrow vein intersects a body of limonite iron ore on the contact of monzonite porphyry and limestone. South of the contact the King James vein has been opened in the general direction of the Dragon vein, but no actual connection has been traced across the contact. The Dragon vein has not been found profitable, though a little lead and copper ore taken from it has been shipped. It is contained in contact-metamorphosed limestone.

About 300 feet east of the Dragon vein in the Dragon shaft another vein has been exposed which possibly corresponds to the Turk vein, opened on the surface farther north, but which has not been found productive.

From the contact the Dragon vein is traceable on the surface and has been opened in the shafts of the Black Dragon, White Dragon, and Governor, all three of which are at an altitude of about 7,050 feet. The strike of the vein is N. 35° E. and the dip is 80°–85° ESE. The vein is narrow. Silicified limestone and barite form the gangue, and galena, enargite, and their oxidation products are the ore minerals. The ore contains also a few ounces of silver and as much as 0.8 ounce of gold to the ton. Ore from several places, particularly intersections with northeasterly fractures, has been shipped, but no large ore bodies have been found.

The persistency of the vein is shown by deep developments in the Dragon tunnel (altitude 6,675 feet), the crosscut from the North Star mine (altitude 6,650 feet), and drifts on levels 6, 8, and 19 of the Iron Blossom No. 1 shaft. On level 8 the vein is 4 feet wide and shows much limonite, copper stains, and a narrow streak of pyrite, enargite, and barite. In places the ore gives high assays in gold. On level 19 (altitude 6,400 feet) the vein intersects the limestone as a tight seam containing a little quartz, galena, and barite.

In the vicinity of the Iron Blossom No. 1 shaft the deposit still maintains its vein character. (See fig. 40, p. 243.) It lies in fine-grained dolomite which dips east or northeast at angles of 20° to 30° and probably should be identified with the Bluebell dolomite; the lowest levels of the shaft, which is 1,900 feet deep, are probably in the Opohonga limestone. Dikes of monzonite porphyry are observed at many places, and at their contacts some mineralization has occurred. In places the limestone is metamorphosed near the contact.

The principal ore bodies begin a few hundred feet south of the shaft but are confined mainly to levels 5 and 6—that is, to altitudes of 6,800 to 6,900 feet. Here they are from a few feet to 80 feet wide, but they contract sharply on the lower levels, and except to the south, in the Governor claim, the vein is not definitely traceable below level 11. Iron-stained croppings show near the shaft, and on level 2 the vein follows locally the contact of a dike. The principal ore bodies (Pls. XXXV and XXXVI, figs. 40–43) are 100 to 150 feet high and 10 to 50 feet wide and extend almost continuously through the Iron Blossom No. 1 ground. The limestone walls are well marked, and the vein consists of silicified limestone that has been brecciated and cemented by a loose sugary quartz and shows in places

abundant limonite stains. Here and there the ore is surrounded by large masses of silicified limestone. On an average the ore may contain $5 in gold and 20 ounces of silver to the ton, with some lead and copper. Smaller bodies of copper ore along the narrow fissure have been mined on levels 6, 7, 8, and 11.

The main ore body continues at the same general horizon and with similar dimensions for 2,100 feet, sinking gradually about 100 feet, or to altitudes between 6,700 and 6,800 feet. Leaching and contraction of volume during oxidation have allowed a part of the roof to give way, and a large cave has been formed above the ore body between No. 1 and No. 3 shafts. In this vicinity no deep exploration has been undertaken, but a parallel and smaller vein, known as the East vein, has been discovered and is locally of considerable importance (Pl. XXXV). In certain parts of its course this vein contains copper with barite and much limonite.

The Iron Blossom ore bodies cross the Sioux-Ajax fault 400 feet south of No. 3 shaft, in a confused and greatly disturbed zone 300 feet wide. From the Bluebell dolomite on the south the drifts break into the upper beds of the Gardner dolomite, including carbonaceous beds at its top, and finally enter the Pine Canyon limestone. The dips of the limestone increase to 40° and even 60°. This faulting finds expression in the extensive silicification of the limestone and in the local interruption of the ore bodies. The first body of ore encountered in the fault zone lies in a transverse or easterly position for a distance of 160 feet and extends 50 feet above and 60 feet below the 480-foot level of the No. 3 shaft (altitude 6,700 feet). About 200 feet farther north the fault is crossed and the ore begins to develop in the coarse gray limestone of the upper members of the Pine Canyon formation, practically along the flat beds of the synclinal axis. To the end, in the Beck Tunnel mine, through the Iron Blossom No. 3, Sioux, and Colorado mines, this wonderful linear body continues without interruption for 5,000 feet straight north, at altitudes ranging from 6,800 to 6,900 feet. This shoot may be considered as a 5,000-foot horizontal pipe formed by the intersection of a vertical fissure with a certain limestone bed that was particularly susceptible to replacement.

No vein is now visible, but nevertheless the ore lies in the direction of the vein, and many northerly fractures which were no doubt followed by the solutions depositing the ore may be noticed. The ore body formed by replacement lies conformably to the stratification and has a width of 20 to 170 feet and a height of 20 to 60 feet. In Iron Blossom No. 3 the dip of the ore is 13°–20° E. Farther north the replaced limestone bed is almost flat.

The dimensions given are those of the stopes, but the deposit is really larger, for in many places the ore is adjoined by large masses of dark fine-grained silicified limestone, which are particularly abundant in the northern and southern parts of the ore body.

In the north end of the Beck Tunnel mine the deposit encounters a number of cross breaks, and there is some evidence that the depositing solutions were diverted from the northerly fissure at this place and followed the cross breaks upward and westward into the Humbug replacement bodies of the Godiva zone. (See Pls. XXXV and XXXVII.) If this inference is correct, there is little use of attempting to find the northward continuation of the Iron Blossom ore body.

The longitudinal section (Pl. XXXVI) shows that the ore pipe lies about 60 feet higher in the Colorado mine than elsewhere, and also that in part of the Beck Tunnel mine it locally sinks somewhat below the prevailing level of 6,850 feet. These slight differences of level are probably due to local diversion of the ore-forming solutions along cross fractures. One marked fault older than the deposit is crossed on the Colorado ground and finds expression in brecciation with but little vertical displacement of the ore.

At the north end of the Beck Tunnel mine, where the ore pipe ceases, several smaller ore bodies occur within the silicified zone and within a vertical interval of 400 feet, giving in cross section a suggestion of a vein. The shaft has been sunk to a depth of 1,140 feet, and a small amount of development work has been done on several levels, but no definite fissure that could be connected with the ore bodies in the upper levels has been found in the lower levels.

The ore in the southern part of this pipe in Iron Blossom No. 3 ground is similar to that near No. 1 shaft but contains more lead and

perhaps less limonite. It is very siliceous and much of it is sugary. The ore shipped contained at most 15 per cent of lead; the so-called siliceous ore contains only about 1 per cent of lead. Both cerusite and galena are present. The silver ranges from 20 to 40 ounces to the ton, and the gold from \$5 to \$6. The sugary and drusy quartz which in places cements the dark silicified brecciated limestone contains some barite plates. There is practically no copper.

In the Colorado and Sioux mines there is much more lead in the ore, which averaged on the whole 45 per cent of lead, with 45 ounces of silver and \$4 in gold to the ton, but considerable masses of low-grade and highly siliceous ores remain both in these mines and in the Beck Tunnel mine. The ore shipped from the Beck Tunnel mine averaged 21 per cent in lead, with 21 ounces of silver, and only about \$2 in gold to the ton. As elsewhere, the ore is largely oxidized and contains drusy or honeycombed quartz.

MINERALS OF THE ORE DEPOSITS.

GANGUE MINERALS.

Quartz (SiO_2). Hexagonal; mostly as constituent of very fine-grained gray or bluish jasperoid replacing limestone or dolomite; in crusts of small crystals on jasperoid or barite; replacing barite.

Chalcedony (SiO_2). Cryptocrystalline; veinlets and spherulites.

Calcite ($CaCO_3$). Rhombohedral; in scalenohedrons in cavities of limestone; in $-\frac{1}{2}R$ rhombohedrons on oxidized ore.

Aragonite ($CaCO_3$). Orthorhombic; in caves and on oxidized ore; prisms and needles; contains a little zinc in places.

Dolomite ($[Ca,Mg]CO_3$). Rhombohedral; coarsely crystalline masses in beds of fine-grained dolomite.

Ankerite ($[Ca,Mg,Fe]CO_3$). Rhombohedral; coarsely crystalline masses in beds of fine-grained dolomite.

Barite ($BaSO_4$). Orthorhombic; white, tabular crystals, in jasperoid or with crystallized quartz.

Gypsum ($CaSO_4$). Monoclinic; slender crystals and thin flakes. Rarely in curling crystals.

Alunite ($K_2O.3Al_2O_3.4SO_3.6H_2O$). Rhombohedral; white earthy or massive, like kaolin; common. Also microscopic in replacement quartz.

Mixed sulphates ($[Mg,Fe,Na_2]\ SO_4+7H_2O$). White efflorescences.

Borickite, basic hydrous phosphate of iron and calcium. Massive; reddish brown; rare.

Crandallite ($CaO.2Al_2O_3.P_2O_5.5H_2O$). Hexagonal (?), white to light gray, shading into yellow and brown; luster dull in compact phase to pearly in lamellar phase; fine botryoidal crusts lining cavities in quartz-barite-sulphide vein; rare; new species.

Sulphur (S). Orthorhombic; yellow crystals and crusts on galena and anglesite.

ORE MINERALS.

GOLD MINERAL.

Native gold (Au). Isometric; bright-yellow flakes; on joint planes of jasperoid in oxidized ore; rare.

SILVER MINERALS.

Native silver (Ag). Isometric; silver-white flakes or wires; not common.

Cerargyrite (AgCl). Isometric; brown or gray waxy coatings, in places with small crystals; common.

Argentite (Ag_2S). Isometric; lead-gray to black; sectile; common but rarely visible to the naked eye.

Proustite ($3Ag_2S.As_2S_3$). Rhombohedral; massive, red, translucent; rare.

Stephanite ($5Ag_2S.Sb_2S_3$). Orthorhombic; iron-black; rare.

Pearceite ($9Ag_2S.As_2S_3$). Monoclinic; rare.

LEAD MINERALS.

Galena (PbS). Isometric; lead-gray; crystalline masses, rarely well crystallized; common.

Geocronite (?) ($5PbS.Sb_2S_3$). Orthorhombic; lead-gray; identified without much doubt in polished section. Replacing galena.

Anglesite ($PbSO_4$). Orthorhombic; colorless crystals lining cavities in galena; grains replacing galena and quartz.

Cerusite[1] ($PbCO_3$). Orthorhombic; white acicular crystals or earthy-white or yellow; common.

Leadhillite ($PbSO_4.2PbCO_3.Pb(OH)_2$). Monoclinic; white crystals with anglesite; very rare.

Cotunnite ($PbCl_2$). Small amounts of lead and chlorine in hot-water solution of some oxidized ores indicate possible presence of cotunnite.

Phosgenite ($[Pb,Cl]_2.CO_3$). Tetragonal; gray replacement crusts on cerusite; rare.

Lead oxychloride (unnamed). Probably orthorhombic; yellow prisms.

Minium (Pb_3O_4). Earthy; vivid red; rare.

Pyromorphite ($[Pb,Cl]Pb_4(PO_4)_3$). Hexagonal; small, slender crystals; white; rare. Contains arsenic.

COPPER MINERALS.

Enargite (Cu_3AsS_4). Orthorhombic; iron-black; one good cleavage; in jasperoid; small crystals in vugs.

Famatinite (Cu_3SbS_4). Reddish gray, intergrown with enargite.

Tetrahedrite ($Cu_8Sb_2S_7$). Isometric; dark gray, massive; in jasperoid; not common.

Chalcocite (Cu_2S). Orthorhombic; blackish lead-gray; secondary; not common.

Covellite (CuS). Hexagonal; metallic blue; secondary; small crystals pulverulent; common.

Chalcopyrite ($CuFeS_2$). Tetragonal; brass-yellow; not common.

Native copper (Cu). Isometric; copper-red; fairly common in small quantities.

Cuprite (Cu_2O). Isometric; red, massive, compact; common.

Melaconite (CuO). Black; amorphous; doubtful.

[1] The spelling "cerusite" has been adopted by the United States Geological Survey. The writer prefers "cerussite," the form used by Dana.

Copper pitch ore ($CuO.SiO_2.MnO_2.H_2O$). Brown or black; dense, amorphous; common. Of indefinite chemical composition; probably of colloid origin. Not a variety of chrysocolla.

Malachite ($CuCO_3.Cu(OH)_2$). Monoclinic; pure green, fibrous; velvety crusts, slender prisms; common.

Azurite ($2CuCO_3.Cu(OH)_2$). Triclinic; azure blue, crystalline crusts or massive; common.

Aurichalcite (basic carbonate of copper and zinc). Pale-bluish druses and flakes; rare.

Chrysocolla ($CuSiO_3.2H_2O$). Cryptocrystalline; massive; blue or green; not common.

Brochantite ($CuSO_4.3Cu(OH)_2$). Orthorhombic; dark green to blackish green; fairly abundant.

Lettsomite (cyanotrichite) ($4CuO.H_2O_3.SO_3.8H_2O$). Capillary crystals in druses; smalt-blue; very rare.

Linarite (basic sulphate of copper and lead). Monoclinic; deep-blue crystals; rare.

Olivenite ($Cu_3As_2O_8.Cu(OH)_2$). Orthorhombic; various shades of olive-green, also red; prismatic crystals; rarely velvety crusts; very common.

Clinoclasite ($Cu_3As_2O_8.3Cu(OH)_2$). Monoclinic; bunches of crystals; spherical forms, one perfect cleavage; dark green with bluish tinge; fairly common.

Erinite ($Cu_3As_2O_8.2Cu(OH)_2$. Dark, dirty green; mammillary or small fibrous spheres; rather uncommon.

Tyrolite ($Cu_3As_2O_8.2Cu(OH)_2+7H_2O$?). Pale green inclining to sky-blue; one perfect cleavage; foliated aggregates and fan-shaped groups; rather uncommon.

Chalcophyllite ($Cu_3As_2O_8.2Cu(OH)_2+14H_2O$?). Rhombohedral; one perfect cleavage; emerald or grass-green; very rare.

Chenevixite ($Cu_2(FeO)_2As_2O_8+3H_2O$?). Massive; greenish yellow; rare.

Conichalcite ($[Cu,Ca]_3As_2O_8.CuCa(OH)_2+\frac{1}{2}H_2O$?). Characteristic bright yellowish green; mammillary crusts and small spheres; very common.

Mixite (basic hydrous arsenate of copper and bismuth). Slender radiating, capillary pale-bluish tufts of crystals; rare.

Connellite (basic hydrous chlorosulphate of copper). Radiating fibrous crystals; bright Prussian blue; almost metallic luster; very rare.

Spangolite (basic hydrous chlorosulphate of copper and aluminum). Hexagonal, thick prisms; pale green to bluish green; perfect basic cleavage; very rare.

IRON MINERALS.

Pyrite (FeS_2). Isometric; small cubes, octahedrons, pyritohedrons or massive; pale yellow.

Marcasite (FeS_2). Orthorhombic; rare.

Arsenopyrite ($FeAsS$). Orthorhombic; massive; grayish white; rare.

Limonite ($2Fe_2O_3.3H_2O$). Dark brown to yellowish brown; fibrous or earthy; common.

Hematite (Fe_2O_3). Rhombohedral; steel-gray with red streak, or red and earthy.

Scorodite ($FeAsO_4+H_2O$). Orthorhombic; bluish-green prisms and pyramids.

Pharmacosiderite ($6FeAsO_4.2Fe(OH)_3+12H_2O$). Isometric; crusts or isolated small brown cubes; not common.

Melanterite ($FeSO_4.7H_2O$). Monoclinic; pale-green crusts.

Jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$). Rhombohedral; yellowish-brown, hexagonal scales; soft; much of the material called "jarosite" is probably plumbojarosite.

Utahite ($3Fe_2O_3.2SO_3.7H_2O$). Scaly; orange-yellow; perhaps identical with jarosite.

MANGANESE MINERALS.

Pyrolusite and wad (MnO and hydrated forms). Black; massive, fibrous, or earthy; common in small quantities.

Manganite ($Mn_2O_3.H_2O$). Black; lamellar aggregates; rare.

ZINC MINERALS.

Sphalerite or zinc blende (ZnS). Isometric; dark brown; massive, rarely crystallized; rare except in veins in monzonite.

Smithsonite ($ZnCO_3$). Rhombohedral; reniform crusts; replacement of limestone; common; with iron carbonate variety, monheimite.

Calamine (H_2ZnSiO_5). Orthorhombic; small crystals and white mammillary forms; fairly common.

Hydrozincite ($ZnCO_3.2Zn(OH)_2$). White; chalky or fibrous; alternating with smithsonite in reniform crusts.

Goslarite (?) ($ZnSO_4.7H_2O$). White efflorescences.

Adamite ($Zn_3As_2O_8Zn(OH)_2$). Orthorhombic; pale-green crusts; rare.

Aurichalcite (basic carbonate of zinc and copper). See above under "Copper minerals."

BISMUTH MINERALS.

Native bismuth (Bi). Rhombohedral; reddish silvery white; rare.

Bismite (Bi_2O_3). Earthy-yellow crusts.

Bismutite ($Bi_2O_3.CO_2.H_2O$). Yellow; earthy.

Mixite (basic hydrous arsenate of copper and bismuth). See above under "Copper minerals."

Arsenobismite ($2Bi_2O_3.As_2O_5.2H_2O$). Yellow; earthy cryptocrystalline; new mineral.

URANIUM MINERAL.

Zeunerite ($Cu(UO_2)_2.As_2O_8+H_2O$). Tetragonal; small uranium-yellow tabular crystals on barite; very rare.

FEATURES OF THE OCCURRENCE OF MINERALS.

In the following paragraphs is given a running comment on the mode of occurrence and special localities of the minerals listed above. The genesis of the deposits and the general course of alteration are discussed in another place.

GANGUE MINERALS.

Quartz.—All the deposits contain quartz, which occurs in two forms. (1) As a fine-grained aggregate replacing limestone or dolomite, the structure and texture of which may be preserved. Some of it contains residual calcite or dolomite. The color is gray or bluish

gray, or both, alternating in delicate banding. Such replacement quartz has often been called jasperoid (Pls. XX–XXII, pp. 157–159). (2) As later crystalline crusts with small crystals, usually projecting only with the pyramidal faces. These crystals are generally not more than a few millimeters long. Longer and thicker crystals may be found on some veins in monzonite. This quartz is of the second generation, preceding oxidation. A third generation of quartz occurs in places, and a fourth generation of small crystals is here and there deposited on products of oxidation. The quartz grains in many varieties of jasperoid are believed to have crystallized from an initial replacement by gelatinous silica, and much of the quartz of the second generation, preceding oxidation, is likewise crystallized from an initial deposit of silica gel. Chalcedony is present as spherulites and veinlets.

Calcite.—Calcite is not a primary gangue mineral, except that residuary masses may be rarely found in jasperoid. In brecciated limestone calcite is abundant in scalenohedral forms; in caves of recent origin calcite in long branchlike crystals and botryoidal masses is very common. Calcite is also one of the latest products of oxidation processes and here appears as flat rhombohedrons.

Aragonite.—In caves of late origin or as bunches of slender prisms, aragonite appears here and there, forming one of the latest products on oxidized ores.

Dolomite.—Minerals allied to dolomite and ankerite are common in brecciated limestone and locally also cement fractures in ore bodies, but they are not ordinarily gangue minerals, properly so called. Crystals of rhombohedral forms are sometimes seen, but ordinarily the minerals form coarse granular aggregates.

Barite.—Barite is an almost universal gangue mineral of both the earlier and later phases of primary mineralization. Large masses of coarsely granular or platy barite aggregates are seen in the Centennial Eureka and Grand Central mines, also in the veins of the Carisa, where at the junction of two veins the barite forms a solid body 25 feet wide, 40 feet or more long, and 50 feet in vertical extent. Large plates of barite several inches long are in places intergrown with sulphide minerals and with quartz. Several generations of barite are often seen; any generation may be partly replaced and coated by quartz, and sometimes the crystal has been entirely dissolved, leaving a cast of the tabular crystal. The perfect crystals are very small. Where the mineral is present in considerable amounts, it is generally associated with the copper-gold ores, particularly with enargite.

Gypsum.—Gypsum belongs to the oxidation phase of the deposits and is widely spread in the oxidized ores. Curved small crystals were found in a cavity in the zinc stopes of the May Day mine. Long, slender crystals were found, according to Tower and Smith, in open spaces in the Ajax veins, and these were coated with stalactites of limonite. Still better crystals of gypsum were found in a cave in Iron Blossom No. 1 (p. 243).

Alunite.—Aluminum sulphates are far more widespread than was expected and are found at many places in the oxidized ores. Inconspicuous white kaolin-like masses of alunite occur in the country rock of some of the deposits—for instance, in a black shale common underneath some ore bodies of the Iron Blossom. Microscopic crystals were found in some of the veins in monzonite and in an outcrop of replacement quartz or silicified porphyry near the Governor shaft.

Crandallite.—A new mineral,[1] with the formula $CaO.2Al_2O_3.P_2O_5.5H_2O$, has been found only on the dump of the Brooklyn mine. It is named crandallite, after Mr. M. L. Crandall, engineer for the Knight syndicate, who rendered much valuable assistance during the writer's study of the mines in the Iron Blossom and Godiva zones and in the igneous rocks. It is a white to yellowish-gray dense to fibrous hydrated phosphate of aluminum and calcium and has apparently resulted from the alteration of a nonfibrous mineral similar to goyazite (hamlinite). The material seen forms fine botryoidal crusts, lining and partly replacing the walls of cavities in quartz-barite-sulphide vein matter. It is coated with a thin layer of tenorite. In part it has a pearly luster on basal cleavage surfaces. Cleavage fragments prove under the microscope to be uniaxial and are believed by Mr. Schaller to represent the

[1] For a complete description with discussion of the chemical and mineralogic relations of crandallite, see Loughlin, G. F., and Schaller, W. T., Crandallite, a new mineral: Am. Jour. Sci., 4th ser., vol. 43, pp. 69–74, 1917.

cleavage of the original mineral (goyazite or hamlinite) whose alteration has yielded crandallite. The cleavage of the finely fibrous to cryptocrystalline crandallite could not be determined; neither could its specific gravity, owing to the impossibility of obtaining material free from associated minerals. The hardness is between 4 and 5. The indices of refraction range from a minimum of 1.585 to a maximum of 1.595. Before the blowpipe crandallite decrepitates somewhat, then exfoliates slightly, and fuses to an opaque white enamel, coloring the flame intermittently a pale green (phosphorus) with occasional flashes of red (calcium, strontium). In a closed tube decrepitation occurs with the liberation of water. It is soluble in acids. The chemical analysis is as follows:

Analysis of crandallite.

[W. T. Schaller, analyst.]

	Analysis.	Recalculated with insoluble matter deducted.
Insoluble matter	35.13	....
Al_2O_3	25.16	38.71
CaO	4.88	7.50
SrO	1.44	2.21
MgO	.61	.94
P_2O_5	17.61	27.09
SO_3	2.47	3.80
H_2O-	.84	1.29
H_2O+	12.26	18.86
	100.40	100.40

Sulphur.—During the earlier survey sulphur was found in the Eureka Hill mine as nearly perfect crystals one-eighth of an inch in diameter coating anglesite that was attached to galena in cavities. It was also found incrusting the walls of the Sioux-Ajax tunnel.

The foregoing list of gangue minerals is unusually short for deposits so complex. Fluorite, siderite, rhodochrosite, chlorite, and zeolites are entirely absent, as is the whole series of silicates, boro-silicates and fluo-silicates of the high temperature deposits.

GOLD AND SILVER MINERALS.

Gold.—Native gold is rarely seen in the Tintic ores, though many of the copper-bearing or purely siliceous ores contain gold to the amount of several dollars to the ton. In the purely siliceous ores—for instance, those of the Iron Blossom No. 1, which are honeycombed and cellular and contain but little limonite—the gold, though present to the extent of several tenths of an ounce to the ton, is very rarely visible. In the enargite ores, which may contain equal amounts, free gold is never seen, and the pure enargite carries about \$8 to \$12 in gold to the ton. According to Tower and Smith,[1] "Special tests on the gold-bearing ores have shown the presence of small amounts of tellurium; that gold is combined only with tellurium is very uncertain. It may also (in the primary ores) have been associated with pyrite." The mines that have yielded most gold are the Centennial Eureka, Mammoth, Grand Central, Victoria, Eagle and Blue Bell, Gold Chain (Ajax), Opohonga, North Star, and Iron Blossom No. 1. Rich gold ores containing many ounces to the ton were found locally in these mines. The largest shoot of gold ore, which contained few other valuable constituents, was found in the Apex shoot of the Mammoth, particularly on the 1,500 and 1,600 foot levels(?). Such ores are quartzose and always show native bright yellow gold, which is clearly of secondary nature, deposited during oxidation as flakes on joint planes (Victoria) or as nests in partly disintegrated and oxidized jasperoid.

Silver.—Native silver is sometimes seen, chiefly in the upper levels of the mines that contain galena, where it is neither plentiful nor conspicuous. It forms small sheets and wires. Secondary wire silver is also found in the Gemini mine on level 19, below the water table; there was some oxidation and one wire was found to penetrate a crystal of cerusite.

Cerargyrite.—Cerargyrite, or horn silver, in thin gray or brown flakes and coatings was exceedingly common in the partly oxidized lead ores. The Gemini and Eureka Hill mines have had large bodies of chloride ore from the surface down to the 800 or 1,000 foot levels. The typical horn-silver ores are siliceous and carry only a small percentage of lead, mostly in the oxidized form. In late years much of this kind of ore has been mined on the 1,200-foot level of the Eagle and Blue Bell mine. Tower and Smith[2] mention the

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 694.
[2] Idem, p. 721.

occurrence of crusts of horn silver half an inch thick in the Gemini mine. The cerargyrite certainly becomes less conspicuous at great depth, and galena appears instead. The writer is informed by Mr. John McChrystal, however, that horn silver was found in level 16 of the Gemini mine, 1,700 feet below the surface.

Argentite.—Argentite is not a rare mineral at Tintic, but it can rarely be identified without the aid of a microscope. It occurs in microscopic grains in all the argentiferous galena of the district. In this form it is primary. Argentite associated with native gold and cerargyrite was found in many specimens of rich ore and is here undoubtedly secondary. As a microscopic product of the replacement of proustite it was observed in a specimen from the Chief Consolidated mine, obtained at a depth of probably about 1,000 feet.

Sulpharsenides of silver.—Proustite occurred in the specimen just mentioned and is doubtless secondary; at any rate it is decidedly later than the latest crustified quartz. "Ruby silver" is reported from level 19 of the Gemini mine but is evidently very rare in the district, a remarkable fact considering the frequent association of enargite with silver-bearing ores.

Stephanite and polybasite are likewise extremely rare if they occur at all. On the other hand, pearceite (exact locality unknown) was found by Mr. Maynard Bixby, of Salt Lake City, in a car of Tintic ores, and crystallized specimens of this mineral are, according to a letter from Mr. Bixby, in the Field Museum in Chicago, in the American Museum of Natural History in New York, and in the Bement collection. The mineral was identified by Penfield. A gray massive mineral probably identical with pearceite occurs abundantly, intergrown with galena, in the Gem shoot in the Gemini mine from level 14 to level 19 (fig. 19, p. 189). It melts easily in the flame of the alcohol lamp and contains abundant silver, arsenic, and sulphur, with some copper. (See p. 179.)

LEAD MINERALS.

Galena.—Galena is one of the most common lead minerals of Tintic and occurs in all the mines, though not abundant in those in which much enargite and barite are present. In such mines galena is sometimes found on the outer side (in the "casing") of ore bodies. The bodies of galena are associated with quartz and a little barite, and some very large ore shoots of almost pure galena have been mined. Tower and Smith mention masses of galena ore from the Uncle Sam mine carrying 75 per cent galena by the hundreds of tons. More recently large quantities of high-grade galena ores from the lower levels in the Eagle and Blue Bell mine have been shipped. The galena rarely forms well-developed crystals, but occurs commonly in crystalline aggregates the grains of which are from 1 to 5 millimeters in diameter. Fine-grained "steel" galena usually occurs in partly oxidized bodies. Much of the galena appears in two generations, connected respectively

FIGURE 17.—Sketch of polished section of ore from Eagle and Blue Bell mine. Galena oxidizing to anglesite. Zinc blende intergrown with galena. Geocronite replacing galena. Covellite developing along anglesite contact.

with the fine-grained jasperoid and the crustified quartz. Locally galena of a still later generation forms films on joint planes. All the galena contains silver but rarely more than 50 ounces to the ton; much of it runs only 30 ounces, and in some of the mines distant from the centers of metallization it may contain only a few ounces. The silver content is dependent upon small included grains of argentite.

Anglesite.—The first alteration product from galena during oxidation is anglesite (fig. 17; Pl. XXVI, *E*, p. 166). It is a widely spread mineral but occurs rarely in large quantities. In the massive form it usually has a dark color caused by finely disseminated galena. The beautiful anglesite crystals from the Eureka Hill mine, which appear as drusy crusts in cavities of galena, are found in many collections.

Cerusite.—The most abundant lead mineral in the district is cerusite. It is common in all the mines, and locally as in the Colorado and Iron Blossom mines, it occurs in very large masses. Anglesite rapidly changes to cerusite under the influence of water containing carbon dioxide. Silky tufts of slender crystals are common in the oxidized ores, but the mineral is more abundant in granular or massive earthy and sandy aggregates of white to yellowish color, in great part directly replacing massive galena. The cerusite invariably contains silver, at least when in granular or massive form. Assays of pure material from the Iron Blossom gave about 20 ounces of silver to the ton.

Other lead minerals.—Leadhillite is known from one occurrence in the Eureka Hill mine, with anglesite; the specimen is in the Holden collection in Harvard University.

Cotunnite, the chloride of lead, may be present in minute quantities in some of the oxidized lead ores which give a trace of lead and chlorine upon extraction with hot water.

Phosgenite, the rare chlorocarbonate of lead, was recently identified by Prof. Charles Palache. It occurs on a specimen of cerusite in the Holden collection as a grayish-brown crust replacing the carbonate. An unidentified oxychloride was determined by Mr. Whitehead and Prof. C. H. Warren on a specimen in the collection of the present survey obtained from the 1,000-foot level of the Eureka Hill mine. It forms minute yellow probably orthorhombic prisms and rounded aggregates. It is soft and rather brittle, fuses easily, and yields lead, chlorine, and a little arsenic.

Minium is sometimes seen as a bright-red earthy coating on oxidized ore and is one of the latest products of oxidation.

Mimetite from Tintic (locality unknown) is contained in specimens of oxidized ore in the Holden collection, but in general arsenates of lead are rare in the Tintic district. Pyromorphite has been identified in specimens from the Eureka Hill mine in the Holden collection. The mineral occurs as slender white needles in vugs and also appears to contain some arsenic.

COPPER MINERALS.

Enargite.—The principal primary copper mineral at Tintic, though relatively rare elsewhere, is enargite. There are few mines in which it does not occur at least in a subordinate quantity. It has been found in the lead mines of the Iron Blossom zone and in the Gemini mine and occurs in large quantities in the Centennial Eureka, Mammoth, Ajax, Gold Chain, Opohonga, Carisa, and other copper mines, also in many of the deposits in the monzonite. To a large extent the enargite has been destroyed by oxidation (fig. 18); but even in the upper levels of the mines mentioned much of it has been found. Considerable enargite was found in the Apex ore body of the Mammoth mine, 100 feet or less from the surface. The enargite occurs mainly in coarsely crystalline aggregates of iron-black color and excellent prismatic cleavage. Some of the individual grains may be 2 or 3 inches in length, being mostly elongated along the prismatic axis. Good but very small crystals were seen on quartz in vugs in ore from the Eureka Hill mine; crystals are also said to have been observed in the Homestake vein and on the dump of the Sunbeam mine in the monzonite area. Enargite is associated with barite and jasperoid, and much of it contains small grains of pyrite and chalcopyrite.

FIGURE 18.—Sketch of polished section of enargite ore from Victoria mine, showing vein of copper arsenates (white) with lining and streaks of chalcocite (dark gray) and later covellite (black).

Famatinite.—In places in the Mammoth mine—for instance, in the Apex ore body, 100 feet below the surface—a metallic mineral allied to famatinite occurs so intimately associated with enargite that pure substance for analysis is difficult to obtain. This mineral is of a reddish-gray color and has a dark-brown streak. A small quantity was analyzed by

George Steiger and found to contain 37.73 per cent of copper, 14.31 per cent of antimony, and 29.07 per cent of sulphur, but Mr. Steiger states that these figures should be regarded as only approximate. It also contains arsenic. Pure famatinite should contain 43.3 per cent of copper, 27.4 per cent of antimony, and 29.3 per cent of sulphur. An arsenical famatinite from Goldfield, Nev.,[1] yielded copper 48.0, arsenic 11.0, antimony 12.2, sulphur 28.8.

Tetrahedrite.—Tetrahedrite is not common in the Tintic district. It was definitely identified from a vein crossing the contact of limestone and monzonite on level 19 of the Lower Mammoth mine, where it is associated with pyrite, zinc blende, and barite. It also occurs in ore from the Gem channel, on level 14 of the Gemini mine, where it is mixed with galena and a little pyrite in a siliceous gangue. In small grains it is common in siliceous copper ore from the Eureka Hill mine. In the earlier report it is said to occur in a specimen from the Black Dragon mine.

Tennantite.—The earlier report mentions tennantite from the Centennial Eureka and Boss Tweed mines, but the identification was not complete. So far, typical tennantite has not been positively identified.

Chalcocite.—In small amounts chalcocite results from the oxidation of enargite and famatinite; it develops contemporaneously with arsenates of copper, particularly olivenite, and is found in many places in small streaks and grains embedded in olivenite and also along the margins of enargite (fig. 18). In larger amounts it has been found only in the Centennial Eureka. In many specimens of enargite it is observed as small sooty aggregates, often with covellite.

Covellite.—Covellite in small amounts is, like chalcocite, a common alteration product of enargite (fig. 18), tetrahedrite, and famatinite. It was found on zinc blende in a specimen from the Black Jack dump and on galena in microscopic grains in specimens from many mines such as the Colorado, Gemini, and Iron Blossom (Pl. XXVI, *C*, p. 166). Like chalcocite, it is the first product of oxidizing alteration and is closely associated with copper arsenates. The Holden collection contains specimens from the Eureka Hill mine showing covellite in minute tabular crystals on anglesite and of almost contemporaneous origin.

Bornite.—Tower and Smith mention one occurrence of bornite, said to form a decomposition product of chalcopyrite. They do not state the locality, and the mineral has not been identified during the present investigation.

Chalcopyrite.—Chalcopyrite occurs sparsely in many of the copper mines and was particularly noted in Centennial Eureka and Grand Central. It is present in small quantities associated with enargite and in places inclosed by it as small anhedrons. It was also observed with pyrite, chalcopyrite, and zinc blende in a vein in monzonite in the Lower Mammoth mine.

Native copper and cuprite.—All of the copper-bearing ores probably contain some native copper and cuprite, but these minerals are rarely conspicuous. Native copper is mentioned as occurring in the Eureka Hill and Boss Tweed mines. During the present investigation it was found in specimens from the Centennial Eureka, intimately associated with cuprite.

Melaconite (tenorite).—In the report by Tower and Smith melaconite is stated to occur abundantly in black earthy masses, but it is probable that most of these are really sooty chalcocite. One specimen from the Brooklyn dump showed a thin coating of tenorite on crandallite.

Copper pitch ore.—The indefinite minerals grouped under the term copper pitch ore, containing oxides of copper, iron, and manganese with silica and water, are common, usually in dense red or brown masses with conchoidal fracture. One specimen from the Ajax dump shows alternating bands of this material with malachite. It is amorphous and of colloid origin.

Malachite and azurite.—The basic carbonates of copper, malachite, and azurite, are rather abundant, though much of the material that looks like malachite is really copper arsenate. Both minerals are formed from enargite, tetrahedrite, and famatinite, but they are usually later products of oxidation resulting from the decomposition of arsenates or from the action of calcium carbonate solutions on soluble copper sulphate. Good specimens of malachite were obtained from the East vein in the deeper levels of the Iron Blossom mine. Neither mineral is particularly characteristic of any given horizon in the mines.

[1] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 118, 1909. Analysis by W. T. Schaller (recalculated).

Brochantite.—The basic copper sulphate brochantite is not common. It is described by Hillebrand and Washington[1] as occurring in small prismatic or double wedge-shaped crystals. The Holden collection contains a specimen from the Centennial Eureka mine.

Lettsomite and linarite.—The blue lettsomite is reported by Dana from the Ajax mine in velvety crusts or globules. Mr. Maynard Bixby, in a recent letter to the writer, states that some very fine lettsomite has recently been found at Tintic. Mr. Bixby also states that linarite specimens, probably from the Bullion Beck or the Gemini mine, are in the Field Museum in Chicago and that recently good linarite is said to have been found in the 800-foot level of the Mammoth mine.

Olivenite.—Of the many copper arsenates found at Tintic olivenite contains the least water, and it is usually the first oxysalt to form during the oxidation of enargite. It is probably the most common of the arsenates. Enargite traversed by a network of olivenite veins is often seen. The mineral appears in many colors and modes of aggregates. It is massive, dense, or crystalline or forms velvety crusts; very commonly it is crystallized in prisms several millimeters in length; more rarely it is tabular, as in a specimen from the Centennial Eureka, identified by Prof. C. H. Warren. In color it is olive-brown, olive-green, yellowish-green, pure brown, or rarely reddish-brown. It occurs in every one of the copper mines at Tintic.

Tyrolite and chalcophyllite.—The pale-bluish foliated and fan-shaped aggregates of tyrolite are found rather commonly in the oxidized copper ores, particularly in the shoots of the Ajax and Mammoth mines; in places the tyrolite occurs with clinoclasite. Chalcophyllite is not easily distinguished from tyrolite; under the microscope the uniaxial character of the former is the most easily available test.

Clinoclasite.—The dark bluish-green clinoclasite, which in many places forms curved or spherical aggregates of rather large size, is one of the characteristic arsenates of the Mammoth-Ajax copper zone but is certainly not common elsewhere. It is generally one of the later arsenates, developed upon olivenite and locally covered by azurite.

Erinite.—Oxidized ores from any of the copper mines may show small dark-green or dirty grayish-green mammillary crusts and spheres of erinite. It is one of the later minerals and, though common, rarely appears in abundance.

Conichalcite.—The arsenates already enumerated are rather free from metals other than copper; 1 or 2 per cent of zinc is commonly present, but there is little iron, calcium, or magnesium—in fact, magnesium is rarely found in more than traces. Tyrolite, however, contains, according to Hillebrand's analysis, 6.84 per cent of CaO, and in conichalcite calcium appears as one of the principal constituents. Hillebrand's analysis of conichalcite[2] shows 19.79 per cent CaO, 0.54 per cent MgO, and 0.36 per cent Fe_2O_3. The mineral is essentially a hydrous arsenate of copper and calcium. Hillebrand found also 0.30 per cent Ag, which is not combined with chlorine but is probably present as a silver arsenate. Conichalcite appears to be a mineral characteristic of the Tintic district; one of the few places of occurrence is at Hinajosa, in Andalusia, Spain, but that variety contains vanadium and no zinc. Dana's handbook incorrectly states that conichalcite resembles malachite; it has, in fact, a very characteristic bright pistachio-green color that should not easily be confounded with the pure green of malachite.

At Tintic conichalcite is probably the most widely distributed copper arsenate and occurs in small fibrous spheres or more rarely in mammillary crusts. It has been observed in all the ore that carries copper, even if mixed with much lead, and always belongs to the later series of arsenates. It develops from the action of calcium carbonate waters on arsenate solutions derived from the earlier series of copper arsenates. In many places the little globules incrust leached quartz from which most of the other arsenates have been dissolved. Hillebrand found it very difficult to obtain pure material for analysis, as most of the little spheres contain a core of gangue material.

Chenevixite.—Ferric arsenate in combination with copper arsenate and water forms the yellowish-brown massive mineral chenevixite, originally described from Cornwall. Chenevixite seems to be a well-established species from the chemist's viewpoint, but its optical

[1] Hillebrand, W. F., and Washington, H. S., Notes on certain rare copper minerals from Utah: U. S. Geol. Survey Bull. 55, p. 47, 1889.

[2] Hillebrand, W. F., Associated rare minerals from Utah: U. S. Geol. Survey Bull. 20, p. 84, 1885.

characteristics have not been determined and it can not be easily distinguished from the massive varieties of olivenite from the American Eagle mine described and analyzed by Hillebrand.[1]

Mixite.—In some of the mines that contain bismuth ores (Mammoth, Ajax, Boss Tweed, and Carisa), tufts of slender crystals of the bismuth-copper arsenate mixite have been found.

Other copper minerals.—Basic copper chlorides and chlorosulphates are rare. Prof. Charles Palache has recently shown the writer specimens of connellite and spangolite from the Grand Central mine. Libethenite, a phosphate of copper, is reported to have been found in the district, but no definite authority for this statement has been obtained.

IRON MINERALS.

Pyrite.—Veins in the igneous rocks generally contain much pyrite, both in massive form and, more rarely, crystallized in octahedrons and pyritohedrons. In finely divided form it is also abundant in many altered igneous rocks both near and distant from veins. The latite and monzonite porphyry at the southern contact contain much pyrite, and it is also common in extremely small grains in parts of the Packard rhyolite and in the dikes in limestone.

In the mineral deposits in limestone and dolomite pyrite is much less abundant. Very little is contained in the lead deposits, and most of that once present has been destroyed by oxidation. Its mode of occurrence seems to be mainly in small crystals of the usual pyritohedral form, inclosed in silicified limestone; in places the conversion of these small crystals to limonite can be readily observed under the microscope. Occasionally small aggregates of massive pyrite are seen.

Pyrite was more abundant in the copper deposits, as shown by the more abundant limonite in the oxidized parts, but in all these deposits and at all depths more or less pyrite remains. It is generally associated with enargite and much of it occurs in small grains and crystals inclosed in that mineral; smaller aggregates of massive texture are often seen. It is not usually intergrown with chalcopyrite.

No secondary pyrite has been observed.

Marcasite.—Marcasite (?) has been noted only in the Gemini mine in the Gem channel, on the 1,400, 1,600, and 1,900 foot levels, mainly below the water level and in association with the peculiar secondary sulphide ore described elsewhere (p. 179). It occurs alone, cementing a breccia of impure dolomite and also with galena, zinc blende, and pearceite (fig. 19) as spherical fibrous aggregates and rounded thin crusts; also in a breccia of silicified rock and dolomite. It may, however, be fibrous pyrite.

Arsenopyrite.—The only occurrence of arsenopyrite is in the pyrite ore of the Swansea mine.

Limonite and other ferric hydroxides.—Limonite is abundant in the copper mines, less so in the lead mines. It is usually yellowish brown and earthy, but in the outcrops—for

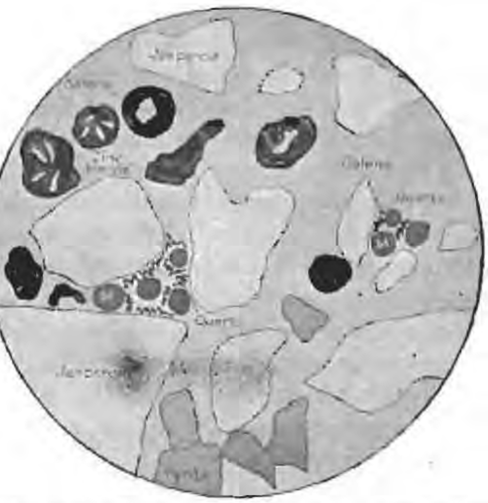


FIGURE 19.—Sketch of polished section of ore from level 19, Gemini mine, showing spherical aggregates of marcasite (?) with quartz.

instance, that of the Eureka Hill mine—it occurs in stalactitic and reniform dark-brown hard masses. In the caves of the Ajax mine stalactites of limonite 2 or 3 feet long were observed by Tower and Smith, covering gypsum crystals and surmounted with calcite crystals.

The other hydroxides may also be present. Mr. Maynard Bixby, of Salt Lake City, reports in a letter that goethite has been found in crystals several millimeters in diameter.

In large dense, fibrous, or earthy masses limonite occurs at the Dragon iron mine, the Black Jack mine, and other places as a replacement of limestone.

Hematite is not commonly seen in the ores from the Tintic district.

Ferric sulphates.—Jarosite is one of the most common of the ferric sulphates and forms a

[1] Hillebrand, W. F., op. cit., p. 85.

bright brownish-yellow, extremely fine scaly powder that sticks to the fingers like graphite when handled. Under the microscope it is seen to consist of minute yellow hexagonal scales. In the Tintic district jarosite was first identified from the American Eagle mine, by Richard Pearce, but this or a similar mineral occurs in most of the oxidized deposits, specifically at the Chief, Grand Central, Iron Blossom, and Colorado mines. Plumbojarosite, which contains lead but no potassium, has been identified from several places, notably the Chief mine, but the identification is difficult because of admixtures with other oxidized lead minerals. Melanterite is found in the Swansea mine as efflorescence and crusts. Utahite, another ferric sulphate without potassium or lead, is stated by Tower and Smith to occur in the Bullion-Beck, Eureka Hill, Mammoth, and Ajax mines. It is orange-yellow and forms hexagonal scales like jarosite, so that the distinction between these sulphates is difficult without chemical analysis on pure material. It is possible that utahite may be identical with jarosite. Efflorescences of mixed soluble sulphates are sometimes found on the walls of the drifts.

Massive sulphates and arsenates.—Massive and very fine grained brown or black ores are often found which are indefinite mixtures of ferric arsenates and sulphates and which also contain more or less copper. Hillebrand [1] analyzed some such materials from the American Eagle mine but found that no definite formula could be calculated for them.

Ferric arsenates.—Iron arsenates are not abundant at Tintic, though scorodite and pharmacosiderite have been identified in specimens from several mines. Fine bluish-green crystals of scorodite from the Centennial Eureka are in the Holden collection. Small brown cubes of pharmacosiderite were noted in several specimens of oxidized ores during the present examination. Mr. Bixby, of Salt Lake City, states that some cubes recently found (exact locality unknown) were 9 millimeters in diameter.

Borickite.—Borickite, a phosphate of iron and calcium, is given by Dana [2] as of doubtful occurrence in the Copperopolis (now Ajax) mine.

[1] Hillebrand, W. F., Associated rare minerals from Utah: U. S. Geol. Survey Bull. 20, p. 87, 1885.

[2] System of mineralogy, 6th ed., p. 1092, 1892.

MANGANESE MINERALS.

Small quantities of oxide of manganese are found in most of the oxidized deposits, particularly in those mines which contain copper and gold. The compound generally present is wad, a hydrous dioxide of manganese. Wad was identified in the Iron Blossom mine in the shale below the ore bodies, and manganite in a specimen from the Victoria mine.

ZINC MINERALS.

Zinc blende (sphalerite).—In the veins in igneous rocks zinc blende is found in places as dark-brown massive aggregates. In the Lower Mammoth vein it appears near the point where the fissure crosses into monzonite. As a rule it is associated with pyrite.

In the primary ore of the deposits in limestone zinc blende is always present, usually as small grains or imperfect crystals embedded in silicified limestone and associated or intergrown with galena (Pl. XXVI, *D*, p. 166). The great bulk of the ore, however, is oxidized, and during the process of oxidation the zinc blende usually is the first mineral to become transformed into sulphate. The mineral is more abundant in the lead ores than in the copper ores. The sulphide ores as shipped contain usually a small percentage of zinc, and from the abundance of oxidized zinc ores near many galena ore bodies the universal presence of 2 to 5 per cent of zinc in the primary ore may be assumed. Below the water level in the Gemini mine a secondary zinc blende is intergrown with galena or forms concentric spherulites (fig. 19).

Oxidized zinc minerals.—During the last few years considerable bodies of oxidized zinc ores have been found adjacent to the old lead stopes in several mines, particularly in the May Day, Uncle Sam, Iron Blossom, Chief, Gemini, and Lower Mammoth. They also occur in the East Tintic and North Tintic districts. Such bodies will probably be found in all the lead mines.

Smithsonite, the carbonate, is the most common of these minerals and forms greenish to white fibrous and mammillary crusts, also gray to brown massive aggregates which are easily mistaken for altered limestone. Fine blue smithsonite is reported from the Boss Tweed or Victor mine.

Calamine, the silicate, forms small tabular crystals; more rarely it has prismatic form; in places it alternates with smithsonite in layers of massive texture. These are generally white, but single crystals are mostly colorless and transparent.

Hydrozincite, identified by Mr. Loughlin, forms white, chalky layers of dense or fibrous texture, alternating with smithsonite.

Aurichalcite, a basic zinc-copper carbonate, is not important as an ore mineral, but its pale-blue scales and rosettes are not uncommon in the zinc ores. Fine aurichalcite was found in the Iron Blossom No. 1 mine and also occurs in several of the properties above mentioned.

All these zinc minerals are associated with calcite, gypsum, and aragonite, and some of the aragonite contains a little zinc.

Adamite, a zinc arsenate, has been found in one specimen from the Iron Blossom mine, on limonite.

BISMUTH MINERALS.

Bismuth minerals have been found at several mines in the district, particularly in the Mammoth, Boss Tweed, Carisa, and Emerald. A composite sample of oxidized lead ores from the Gemini, Victoria, Eagle and Blue Bell, and Colorado mines yielded a distinct trace of bismuth. The metal is thus probably present in most of the Tintic ores. No bismuthinite (bismuth sulphide) has yet been identified, but the earlier report states that native bismuth occurs in the Emerald and Boss Tweed mines; in the Emerald small crystals of the metal were found on limestone in the 500-foot level apart from any known ore body or vein material.

Bismutite, a basic carbonate, is stated by Tower and Smith to occur in the Boss Tweed mine in very considerable bodies assaying from 5 to 40 per cent metallic bismuth. It is said to be an isotropic straw-colored mineral which effervesces freely with acid. Bismuttite also occurs as yellow crusts on rich hornsilver and argentite ores in the Victoria and Eagle and Blue Bell mines. Bismite (Bi_2O_3) has been identified without much doubt in yellow earthy crusts on ore from the 1,200-foot level north in the Eagle and Blue Bell mine.

In 1914 a new discovery of bismuth ore was made in the Mammoth mine on the 600-foot level. A face 18 inches wide contained, according to statements of the officers of the mine, 16.2 per cent of bismuth, 5.7 per cent of copper, and 121.6 ounces of silver and 0.88 ounce of gold to the ton. Another assay across 16 inches yielded 18.12 per cent of bismuth, 2.6 per cent of copper, and 153.7 ounces silver and 0.64 ounce of gold to the ton. A picked sample of yellow ore contained 32 per cent of bismuth and some green copper ore yielded 2.08 per cent of bismuth, 19.3 per cent of copper, and 44.5 ounces of silver and 1 ounce of gold to the ton. This ore has been carefully examined by A. H. Means and found to consist mainly of bismuth arsenate with barite.

The mineral was separated as far as possible from the barite; it forms yellow cryptocrystalline aggregates. The specific gravity of the pure material is 5.70; the refractive index close to 1.60. An analysis by R. C. Wells [1] gave the formula $2Bi_2O_3.As_2O_5.2H_2O$, and the mineral was named arsenobismite.

Gold, silver, and bismuth have probably been concentrated in this ore by the action of oxidizing processes. The neighboring Opohonga mine also contains bismuth, for an output of 4,099 tons of ore yielded from 0.28 to 0.60 per cent of bismuth.

A bismuth oxychloride that is probably identical with daubréeite was found by Mr. Means [2] on a specimen from the 1,200-foot level of the Eagle and Blue Bell mine. The mineral occurs as small hexagonal prisms.

Mixite, a basic copper-bismuth arsenate, forms bunches of delicate bluish-green needles and has been found in the Ajax, Mammoth, Boss Tweed, and Carisa mines.

URANIUM MINERAL.

So far as known neither uranium nor vanadium is commonly found in the ores of the Tintic district. Minute yellowish-green tabular crystals of zeunerite, a hydrous copper-uranium arsenate, are found in some of the barite in the ore of the Centennial Eureka mine.

THE ORES.

The general character of the ores is described on page 125. In this section it is proposed to present their composition and texture in a more detailed manner. The character of the primary ore will be first set forth; the changes in this ore due to oxidation will be taken up later.

[1] Means, A. H., Some new mineral occurrences from the Tintic district: Am. Jour. Sci., 4th ser., vol. 41, pp. 125–130, 1916.
[2] Idem, p. 126.

GENERAL OCCURRENCE.

The principal ore deposits of the Tintic district are contained in the Paleozoic limestone and dolomite. In the southern part of the district igneous rocks predominate and, being of later age, cut off the sediments of the northern part. The igneous rocks in the mining district proper are mostly intrusive and consist mainly of monzonite, monzonite porphyry, and the Swansea rhyolite. All these rocks contain ore-bearing veins. In general the veins strike in a northeasterly direction and are continued in the vein zones of the sedimentary area on the north. (See Pl. IV, in pocket.) The Iron Blossom zone continues almost without interruption across the contact, though no single vein can be traced from the igneous into the sedimentary rock. In the Iron Blossom mine the vein for some little distance follows the contact, which locally trends north. In at least one place in the Mammoth zone, however, at the Lower Mammoth mine, the vein is traced uninterruptedly across the contact.

The mineral composition of the veins in monzonite and in the porphyries is practically identical in character with that of the copper deposits in the limestone. Barite and quartz are the gangue minerals; pyrite and enargite with a little galena and zinc blende are the ore minerals. Pyrite, however, is much more abundant than in the deposits in the limestones.

The evidence is conclusive that the veins in limestone and those in the igneous rocks are of the same age and were formed by the same agencies, the epoch of vein formation following shortly after the intrusion of the monzonite. This conclusion does not agree with that presented in the earlier report, in which it was assumed that the veins in the sedimentary rocks antedated the intrusion of the monzonite. The evidence for the view here set forth was obtained from mine workings opened since the field work for the earlier report was done.

ORES IN IGNEOUS ROCKS.

ALTERED MONZONITE AND MONZONITE PORPHYRY.

Along the veins the monzonite and monzonite porphyry have undergone a marked alteration. Close by the vein contacts they have been completely replaced by quartz accompanied by a little sericite and pyrite. As distance from the vein increases silicification is less complete, the quantity of sericite increases, and the pyrite, though still present in small quantity, is in places more conspicuous. Still farther from the main veins the quantity of replacement quartz and sericite diminishes and chlorite, epidote, and calcite are present. Pyrite is persistent. The altered rock is much shattered and recemented by networks of veinlets containing quartz with a little pyrite and chalcopyrite. The copper content, so far as known, is too small for the rock to be of value as a low-grade ore.

Nearly the whole area of these igneous rocks shows alteration to a greater or less degree. A considerable part of the rock at the surface has been so bleached by weathering that its exact identity can not be determined. The principal area of bleached rock extends northeastward along the chief vein zones, and a continuation of it is seen in the rhyolite area east of the Colorado mine.

In the following table is given a chemical analysis of the sericitized monzonite porphyry (column 1) from the vicinity of the Dragon iron mine, together with one of relatively unaltered monzonite (column 2) obtained near the Iron Duke mine. Both analyses were made by H. N. Stokes.

Analyses of altered monzonite porphyry and relatively unaltered monzonite.

	1	2
SiO_2	71.14	59.76
TiO_2	.75	.87
Al_2O_3	16.24	15.79
Fe_2O_3	.94	3.77
FeO	.16	3.33
MnO	Trace.	.12
CaO	.25	3.88
SrO	Trace.	Trace.
BaO	.05	.09
MgO	1.12	2.16
K_2O	4.96	4.40
Na_2O	.07	3.01
Li_2O	Strong trace.	Trace.
H_2O at 110° C.	.49	.31
H_2O above 110° C.	2.74	1.11
P_2O_5	.32	.42
V_2O_3	.02	.02
CO_2	None.	.78
Cl	Trace.	Trace.
SO_3	.26	Undet.
	99.51	99.82

Comparison of these analyses shows that the alteration is of the character usual in sericitized rocks. Silica, potash, water, and probably sulphur have been introduced; soda, iron oxides, lime, magnesia, and minor constituents have been largely removed. The removal of iron oxides is in keeping with the marked increase of silica, which implies rather intense alteration. The iron represented in this analysis, however, may be below the average, for determinations of the pyrite content in five samples of altered rock from a drill hole near the Brooklyn shaft showed it to range from 2.5 to 7.71 per cent (average, 5.17). How much of this pyrite was actually in the rock and how much in veinlets is not known. This pyrite contained 9.7 per cent of copper, equal to 0.5 per cent of the original rock.

VEIN MATTER AND FILLING OF VEINS IN IGNEOUS ROCKS.

DEVELOPMENT.

The veins in the igneous rocks are short and numerous. Only one of them has been worked to a depth exceeding 500 feet, and the production, though coming from a great number of deposits, has been insignificant compared to the yield of the deposits in the limestones or dolomites. A small output has always been maintained, most of it from the Swansea mines. Of the other mines the Sunbeam, Undine, Brooklyn, Shoebridge, and Old Susan have at times yielded some ores. In 1908 the ore produced from mines in the igneous area amounted to 1,141 short tons.

During 1911 the Swansea mine was the only large mine in igneous rock doing systematic work. A few were being worked under lease, but only one of these, the Old Susan, southwest of Sunrise Peak, was visited. The reasons given for the idleness of the larger mines were the exhaustion of oxidized ores at ground-water level and the small size and irregular occurrence of the pay streaks in unoxidized ore, which were not valuable enough to offset the expense of pumping the large volume of water struck in the deeper workings. Most of the mines were idle when the first survey was made, and almost nothing can be added to the descriptions of them in the earlier report. Examination of the dumps of some of these mines afforded an opportunity to study the character of their ores.

STRUCTURAL FEATURES.

The deposits thus far worked are all in veins of varying length in vertical or nearly vertical sheeted zones. The dip of the veins is steep, and the general trend of most of the main fissures is north-northeast to northeast, parallel to the long axis of the monzonite mass. The Swansea fissure trends a little west of north, but this, too, parallels the contact between the monzonite and rhyolite porphyry. In some places two main fissures unite directly, and in a few places two such fissures are connected by cross fissures of northwesterly or northeasterly trends. Only a very few scattered veins were studied south of the area shown on the map of the Tintic mining district (Pl. IV, in pocket). These seem to have a tendency to radiate from the summit of Sunrise Peak.

MINERAL COMPOSITION.

The statements here made as to the mineral composition of the veins are based on a study of the Swansea vein and of material on the dumps of the larger mines, especially the Brooklyn, Martha Washington, and Sunbeam. The ore minerals found are, in the order of abundance, pyrite, galena, and enargite, with a very little chalcopyrite, zinc blende, and arsenopyrite. Tetrahedrite also was noted by Tower and Smith [1] in one of the New State (United Tintic) veins. Silver and in some places gold are present in these minerals. The gangue minerals are principally quartz, barite, and the minerals of the wall rock, more or less completely replaced by quartz and sericite. Alunite is present as a minor microscopic constituent.

Of these ore and gangue minerals, quartz and pyrite occur both in the vein fillings and in the wall rock at a considerable distance from the main veins. In fact, all the igneous rocks inclosing the veins south and south-southwest of the Dragon mine practically as far as Diamond Gulch are distinctly silicified and impregnated with pyrite. The same silicified and pyritized zone extends northeastward from the Dragon mine to the hills north and east of Ruby Canyon. The quartz that fills openings is generally crystallized as small prisms and lines the cavities; that which replaces the wall rock is fine grained and of cherty appearance. The pyrite in openings forms small pyritohedrons, cubes,

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 764.

and in some places octahedrons. It is also present in massive form in the veins proper, and the adjacent impregnated rock contains scattered shapeless grains, the largest of which have some approach to pyritohedral or octahedral outlines.

Sericite is inconspicuous or absent in fissure or cavity fillings but is abundant throughout the silicified and pyritized zone. In fact, the rock of this zone is essentially a quartz-sericite aggregate with an irregular though as a rule considerable amount of pyrite. This rock at the surface has weathered or bleached to a chalky-white color, stained in places by brown iron oxide. Sericite extends even beyond this zone and, with chlorite (pennine and delessite), is found in microscopic crystals throughout the igneous rocks of the district.

The other ore and gangue minerals are confined to fissure and cavity fillings or to completely replaced rock close by or within the stronger veins. Barite is widely distributed and is especially prominent in the veins south-southwest of the Dragon mine. In some specimens it appears quite as conspicuous as quartz, but it is absent in the Swansea vein. It forms flat tabular crystals in roughly radiating groups that interlock in a network the interspaces of which are partly or completely filled with quartz, pyrite, and enargite. The microscopic alunite seen is also confined to fissure fillings or to thoroughly replaced rock, in contrast to sericite. Both of these minerals have been found in the same thin section, the alunite in the vein quartz and the sericite in the immediately adjacent wall rock.

Enargite, so far as seen, is limited to portions of the veins that carry barite. It occurs in local concentrations or shoots which are vertical or pitch steeply on the plane of the vein. The enargite is in rather coarsely granular masses, in which single grains present glistening elongate cleavage surfaces; around cavities it develops twin crystals, most of them coated with some green secondary copper mineral. Along the margins of these shoots enargite and pyrite are intergrown in varying proportions.

Galena, like the enargite, occurs intergrown with pyrite around the margins of elongate shoots, but it has no definite relations to other ore or gangue minerals. In the Homestake and Joe Bowers No. 2 mines on Treasure Hill, according to the earlier report,[1] galena and enargite occur together, and in the Joe Bowers No. 2 galena is also present in the upper workings above the limits of the enargite. In the Swansea mine much galena has been mined, but no enargite or barite, so far as known. Enargite and barite appear to be lacking also in the Old Susan mine, southwest of Sunrise Peak.

Silver is highest as a rule in the galena and enargite shoots; but pyrite in parts of the Swansea mine is said to carry enough silver to make ore.

The gold as a rule is rarely visible to the naked eye, and the assays show that it is not abundant in the ores; it can not be definitely said to be associated with any particular mineral. Pyrite, enargite, and galena have all been said to carry gold in different mines.

Chalcopyrite, zinc blende, and arsenopyrite are too scarce to give any definite idea of their modes of occurrence. Chalcopyrite and zinc blende are probably intimately mixed in very small quantity with the other ore minerals; a few small prismatic crystals of arsenopyrite have been detected in a specimen of Swansea ore. One specimen found on the Martha Washington dump contained a few aggregates of zinc blende crystals grown upon a vug lining of quartz crystals and inclosing a core of pyrite. These crystals of zinc blende are clearly of later growth than the quartz and pyrite.

The secondary ore minerals have been chiefly lead carbonate, with a few copper minerals and probably some horn silver, but practically none were found on the mine dumps during the recent survey other than the few already mentioned. A small amount of crandallite, a hydrous calcium-aluminum phosphate, was found associated with green secondary copper minerals and melaconite in a specimen from the Brooklyn dump.

Some idea of the composition of these ores may be given by the following averages of smelter returns:

[1] Tower, G. W., Jr., and Smith, G. O., op. cit., p. 705.

Smelter returns on ores from Tintic district.

Mine.	Gold.	Silver.	Copper.	Lead.		Speiss.	Silica.	Iron.	Sulphur.	Zinc.	Lime.
				Wet assay.	Fire assay.						
	Oz.	*Oz.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Homestake (average of 2 assays)	0.18	12.0	11.15	None.	None.	11.3	21.7	22.1	32.0	0.9	0.0
Brooklyn (average of 8 assays)	.09	39.9	3.94	0.5	....	4.32	40.4	20.9	20.9	.4	.0
Undine (average of 3 assays)	.05	28.1	2.61	24.6	24.9	6.7	16.0	20.8	21.4	1.1	.9
Shoebridge (average of 2 assays)	.02	35.5	1.78	13.7	13.5	.4	25.8	9.1	12.0	1.0	.3
Swansea (average of 15 assays)	.03	30.7	.26	11.6	13.5	2.9	19.0	31.0	31.4	.9	.5

Some of the shipments represented by these figures doubtless were mixtures of primary and secondary ores, and comparisons of the relative quantities of the different metals should be made with this fact in mind; but the high percentages of sulphur and its general predominance over iron show that primary ores made up the bulk of the shipments. Gold appears independent of silver but shows the same approximate variations as copper and would thus appear to occur chiefly in the enargite. Silver shows no definite relation to either copper, lead, or iron, perhaps because the presence of a small amount of secondary horn silver has materially increased the total silver in places where the original silver-bearing minerals are not prominent. This would appear to be the case in the Brooklyn mine, where the silver is highest, the copper low, and the lead practically absent. The copper and lead, according to these figures, have as a rule occurred separately; but although the figures for the Homestake mine give no lead, the description of the mine, as well as of the neighboring Joe Bowers mine, in the earlier report[1] states that enargite and galena are present together. The ratio of speiss (arsenides) to copper is marked in most of the analyses. In the Swansea mine, where copper is practically absent, the speiss evidently represents the small amount of arsenopyrite in the ore. The small yet rather constant amount of zinc is noteworthy. The zinc is independent of copper, and thus appears to have been present as zinc blende rather than a minor constituent of enargite. The very small quantity of lime again indicates that the gangue contains only a very little dolomite or calcite.

PARAGENESIS.

The intimate associations of the different ore and gangue minerals indicate that they crystallized for the most part simultaneously. Quartz and pyrite, both of which impregnate the wall rock and form the edges of fissure fillings, may have preceded the other minerals, but they continued to crystallize through a considerable period. Barite began practically at the same time as the quartz and pyrite but grew more rapidly, and during a relatively short period, for barite crystals whose ends on the cavity wall are parallel with crystals of quartz and pyrite are themselves coated along their sides and partly replaced by crystals of the other two minerals. The enargite and galena, as stated above, tend to be concentrated into shoots, and may be as a whole of somewhat later growth; but where they are in contact with pyrite they are mutually intergrown with it and must at least have begun to crystallize while pyrite and quartz were still forming. The few crystals of arsenopyrite and chalcopyrite are scattered among granular masses of pyrite and must have crystallized along with the pyrite. Zinc blende may show the same relation, but in the one specimen found with prominent blende crystals the blende was of distinctly later growth than both quartz and pyrite.

ENRICHMENT.

Little can be said about the secondary vein minerals, beyond a repetition of the statements in the mine descriptions of the earlier report[2] that the veins above water level had altered to limonite with carbonates of lead and locally of copper, containing considerable silver in a porous mass of quartz. This alteration con-

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 765.

[2] Idem, pp. 757-766.

centrated the valuable metals above water level into rich ore bodies, in the same veins that below water level have proved to contain only meager shoots of pay ore, too small to yield profits over the additional expense of handling large quantities of water.

POSSIBLE LOW-GRADE DEPOSITS IN ALTERED ROCKS AROUND THE VEINS.

The silicified and pyritized rock inclosing the vein zone is found on close inspection to be much shattered and recemented by a network of veinlets, many of them of microscopic size. Some of these veinlets consist almost wholly of quartz, others largely of pyrite, and some of chalcopyrite. The bleached rock at the surface is mostly leached of metallic minerals, and its sericite has been changed largely to kaolin. There is some possibility, therefore, that in places, downward concentration of copper originally in pyrite and chalcopyrite may have formed workable deposits, but the small amount of diamond drilling done by the Dragon Consolidated Mining Co. has not yet produced very encouraging results in this respect. A vertical hole was drilled by this company in the gulch about 440 feet east-southeast of the Brooklyn shaft, passing through 531 feet of porphyry before reaching any limestone. Four samples of the porphyry core between depths of 43 and 68 feet were crushed and panned with the following results:

Pyrite in samples of porphyry from hole drilled in gulch near Brooklyn shaft.

Depth.	Weight (grams).	Pyrite (per cent).
43 to 48 feet	100	4.7
48 to 53 feet	100	2.5
58 to 63 feet	200	5.78
63 to 68 feet	200	7.71
		20.69
Average		5.17

Another 100-gram sample from a prospect tunnel close to the surface and close to or in a fissure zone was also panned, yielding 4.22 per cent of pyrite. The average copper content of the five samples was 0.5 per cent of the original or about 9.7 per cent of the pyrite concentrates. These samples, although taken above water level, indicate that oxidation, below the gulch level at least, is very slight. Holes drilled in higher ground, which is more leached at the surface, may show somewhat higher percentages in oxidized ore within the first 100 feet, but the figures just given should be more representative of the whole ground, and the copper content in these samples is lower than the content in the workable disseminated ores of the Bingham type. The lowest grade of developed ore in the Utah copper mine at Bingham in 1911 contained 1.28 per cent.[1] The average copper content in that year was 1.53 per cent. In 1914 it was 4.25 per cent, of which 66.04 per cent, or about 0.95 per cent of the ore, was saved.[2] Ore mined in 1911 yielded 20 cents to the ton in gold and silver; that mined in 1914 yielded about 13 cents. The same ratio of saving from the sampled portion of the porphyry in the Tintic district would amount to only 0.35 per cent of the ore, or a little over one-third the amount saved at Bingham. Further prospecting, of course, may disclose ground of higher grade, and the only conclusion now warranted is that a workable deposit of low-grade disseminated copper is a possibility but that the evidence at present is unfavorable.

ORES AND VEIN MATTER IN THE DEPOSITS IN SEDIMENTARY ROCKS.

SILICIFICATION OF LIMESTONE AND DOLOMITE. FIRST PHASE OF MINERALIZATION.

The first phase of the mineralization consisted in the replacement of limestone and dolomite by silica, barite, pyrite, galena, enargite, and other minerals. Practically all the ore bodies except those consisting of almost massive galena or lead carbonates are siliceous, the gangue consisting of quartz and barite. Barite is very abundant in some of the copper ores—for instance, in certain places in the Centennial Eureka mine.

The silicified limestone or dolomite is usually a fine-grained gray or bluish-gray rock ranging to dark gray and black. In the southern mines of the district, most of which carry copper, much of it is of coarser grain, some resembling a fine-grained quartzite. In the lead mines it is in places of flinty or cherty

[1] Butler, B. S., The production of copper in 1911: U. S. Geol. Survey Mineral Resources, 1911, pt. 1, p. 53, 1912.

[2] Butler, B. S., Copper in 1914: U. S. Geol. Survey Mineral Resources, 1914, pt. 1, p. 587, 1915.

appearance. The rock usually contains at least a few prisms of barite and probably always carries at least a trace of silver. Galena or enargite may be present in the silicified rock—the jasperoid—in large enough quantity to make the material an ore, but the greater part of the metallic minerals of the deposits were probably introduced during the second phase of the mineralization.

Jasperoid with little metallic content surrounds many of the ore bodies, and in places, as in the Beck Tunnel and Iron Blossom mines, these masses of silicified limestone or dolomite are of large size and extend for 100 feet or more from the ore.

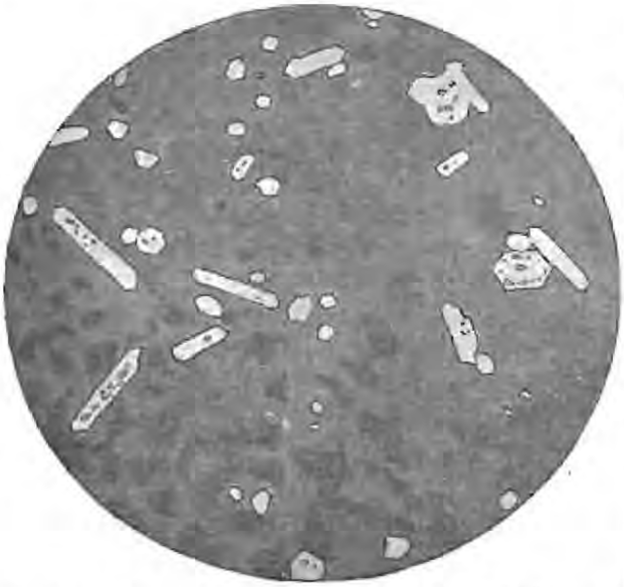


FIGURE 20.—Incipient silicification of limestone, Aspen, Colo. Enlarged 30 diameters.

J. D. Irving [1] was the first to call attention to the fact that there are two kinds of silicification connected with the formation of ore deposits. In some deposits silicification is a gradual process. Beginning with the development of quartz crystals at numerous points (fig. 20) these crystals increase in size and numbers, and finally the whole rock becomes a mass of fine-grained quartz (fig. 21). In other deposits, such as the replacement deposits of the Black Hills, the boundaries of the silicified material are sharp, and all the rock from the fissure to the final limit is completely replaced. No transition rocks are found. The replacement advanced like a wave over the country rock until the impulse was exhausted.

The silicification in the Tintic district is clearly of the latter type. It is almost impossible to obtain a specimen showing transition or a partly silicified limestone or dolomite. The boundaries are everywhere sharp.

In places fragments of dolomite are included in the jasperoid. In specimens of this kind from the Gemini and Iron Blossom mines the contacts of these fragments are distinctly outlined, even when observed under the microscope. A few small quartz grains may be included in the dolomite close to the contact, and some minute residuary carbonate

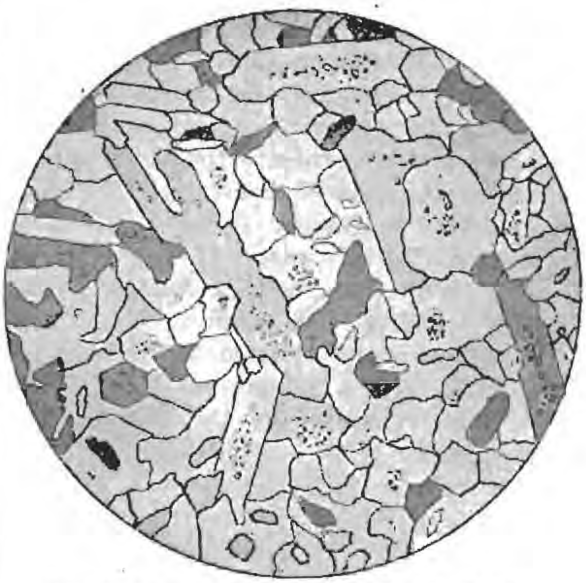


FIGURE 21.—Silicified limestone (jasperoid), Aspen, Colo.

grains lie in the jasperoid. Nowhere does the silicification begin—as it does at Aspen, Colo., and many other places—by the gradual development of quartz crystals in the carbonate rock.

Some of the silicified material from the Centennial, Mammoth, and other copper mines shows, under the microscope, a fine-grained allotriomorphic texture, the quartz grains being sharply outlined and approximately of the same size, averaging about 0.1 millimeter in diameter. Jasperoids from other mines may also consist of grains of corresponding coarseness, but this is usually caused by quartz deposition of the second phase.

Typical specimens of jasperoid show under the microscope a very fine grained aggregate of quartz, the individual grains being rarely over 0.025 millimeter in diameter and ranging from

[1] Some features of replacement ore bodies and the criteria by means of which they may be recognized: Canadian Min. Inst. Jour., vol. 14, p. 422, 1911; Econ. Geology, vol. 6, pp. 556, 558, 1911.

this down to material which is hardly resolved by objectives of the highest power. The grains are closely interlocked, and each one shows undulous extinction, indicating fibrous texture. In some sections the minute grains seem to be rounded or globular. Rapid variations in size of grain are seen at many places. A narrow banding due to the distribution of the sulphides is very common, and here and there it is concentric and independent of fissuring or stratification. This aggregate is usually slightly brownish and turbid, in part probably from finely distributed organic matter, and locally contains small grains of pyrite, galena, and yellow zinc blende. In the copper mines it contains well-formed but small crystals of pyrite and some large crystals of enargite. All the sulphides seem to be later than the quartz aggregate and replace it. Small prisms or plates of barite are present in much of the rock and are evidently the earliest product of the replacement of limestone. The succession is then in general (1) barite, (2) quartz aggregate, (3) sulphides. If any succession can be observed among the sulphides pyrite is usually found to be the earliest.

A typical specimen from the Gemini mine (Pl. XIX, *A*) is a fine-grained brownish-gray rock, faintly banded by the distribution of extremely fine grains of galena. The material under the microscope proves to be quartz, in grains whose diameter does not exceed 0.025 millimeter. In this are disseminated abundant rounded grains of yellow zinc blende and larger grains of galena, at most 0.05 millimeter in diameter. Both sulphides in places show a suggestion of crystal form, and though grains of both may be attached to each other they never show intergrowth. There is no pyrite. This material constitutes in part the lowest-grade ore in the mine.

The strongly banded jasperoid is represented by a specimen from the Gemini mine (Pls. XVIII, *B* and XIX, *B*). This is a cherty bluish-gray rock delicately and beautifully marked by alternating light and dark bands. The dark bands are 0.2 to 0.3 millimeter in width, the light bands about 0.6 millimeter. The banding, though curved in places, keeps its direction through a large part of the specimen, but the banded rock merges into ordinary jasperoid without banding. Under the microscope the rather sharply defined dark bands consist of very fine grained quartz, with allotriomorphic texture and no marked undulous extinction. They contain a few cubes of pyrite, yellow zinc blende in small, rounded grains, and more irregular grains of galena. The light bands consist of spherulites of light-brown chalcedony containing small specks of sulphides. They are separated by clearer granular quartz bordering sharply against them. Much of this clearer quartz shows wavy extinction, and in places the spherulites have been changed to granular quartz with similar wavy extinction. The effect is exactly that of diffusion rings or rhythmic precipitates similar to those in agate described by Liesegang [1] and those produced artifically by the same author.

The jasperoid is of the same nature throughout the district, though the finest grained and the banded varieties are confined to the lead deposits in the northern half of the district, while in the southern part there is much more white quartz of the second phase.

To account for these phenomena the following explanation is proposed.

Silicification of the Tintic type is produced, not by metasomatic replacement, involving the development of crystals in solid rock, but by a replacement of limestone or dolomite by colloidal silica, which immediately afterward became transformed into chalcedony or in part into granular quartz. Such a colloidal mass would be easily penetrated by electrolytes, which by reaction with residuary solutions contained in the gel might easily produce such rhythmic precipitation rings as are shown in the Tintic rock. The ordinary law of replacement by equal volumes would scarcely hold in such a process. The resulting mass would at first be soft, easily compressed and crushed, and the crystallization of the gel would involve a considerable contraction of volume.

The work of Hein, Leitmeyer, and others [2] led to the conclusion that chalcedony is invariably composed of quartz fibers and that it results from the crystallization of gelatinous silica either in the formative stage or at a later time, and that gelatinous silica may in becoming crystalline turn into either granular

[1] Liesegang, R. E., Geologische Diffusionen, p. 180, Wien, 1913; review by Adolph Knopf in Econ. Geology, vol. 8, p. 803, 1913.

[2] Summarized in C. A. Doelter's Handbuch de Mineralchemie, Band 2, pp. 165-190, 240-264, Wien, 1914.

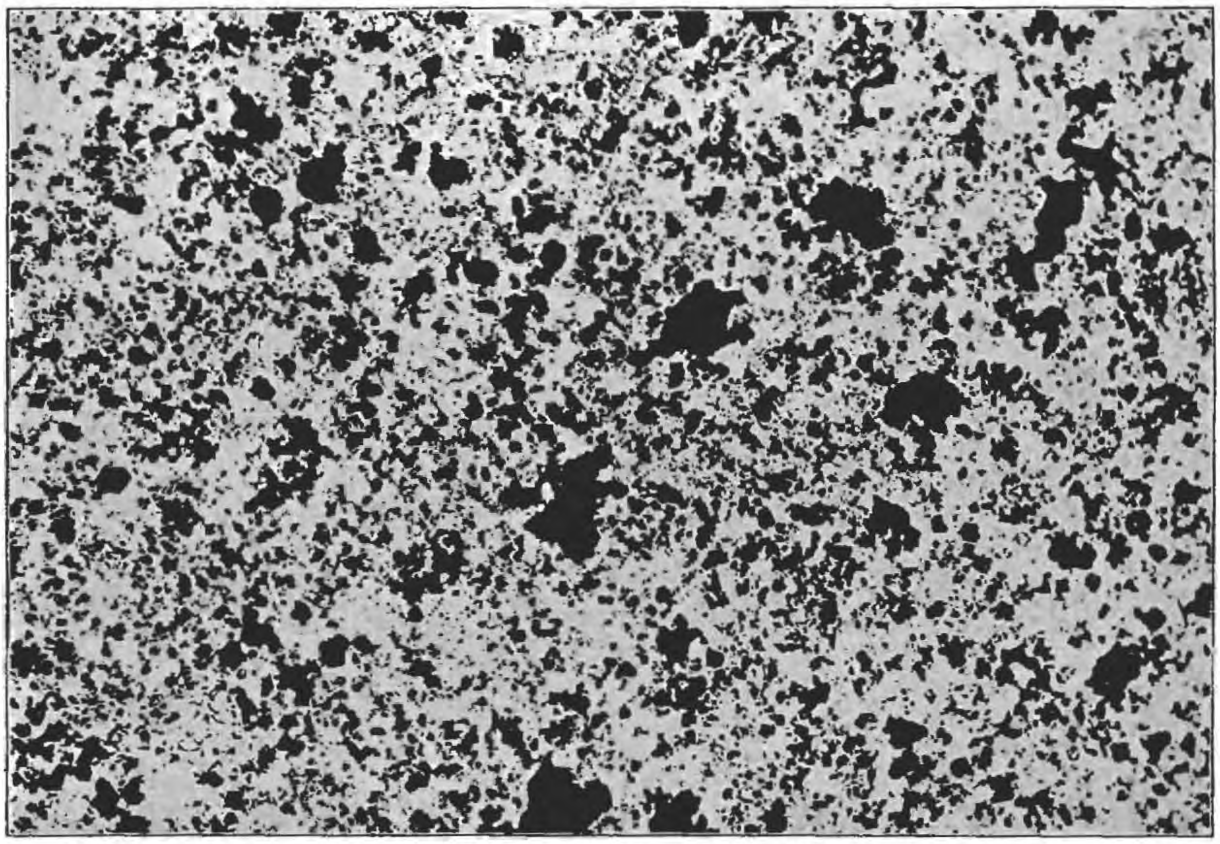
A.

B.

SPECIMENS OF BANDED JASPEROID.

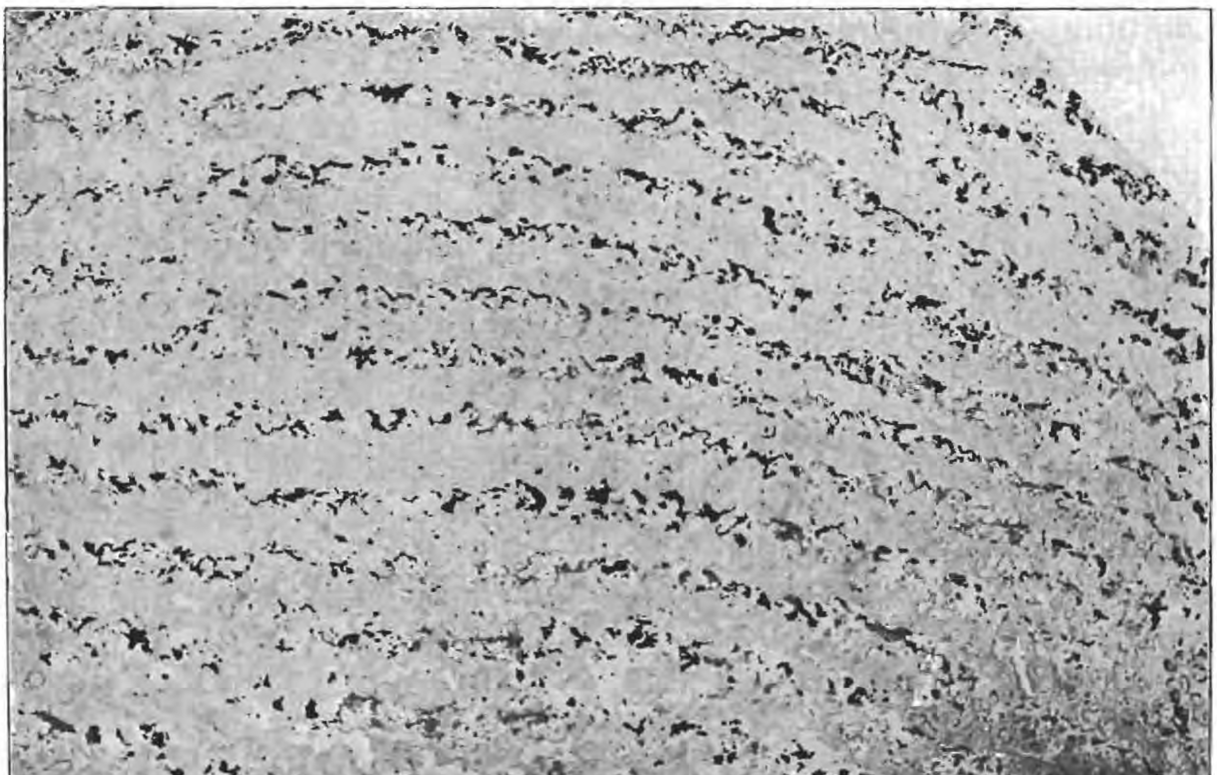
A. Brown jasperoid, Eagle and Blue Bell mine; injected with quartz of second phase. Natural size.

B. Gray banded jasperoid, Gemini mine. Natural size.



A. GRAY JASPEROID, GEMINI MINE.

Black areas are grains of galena and zinc blende; galena mostly in larger grains. Magnifed 150 diameters.



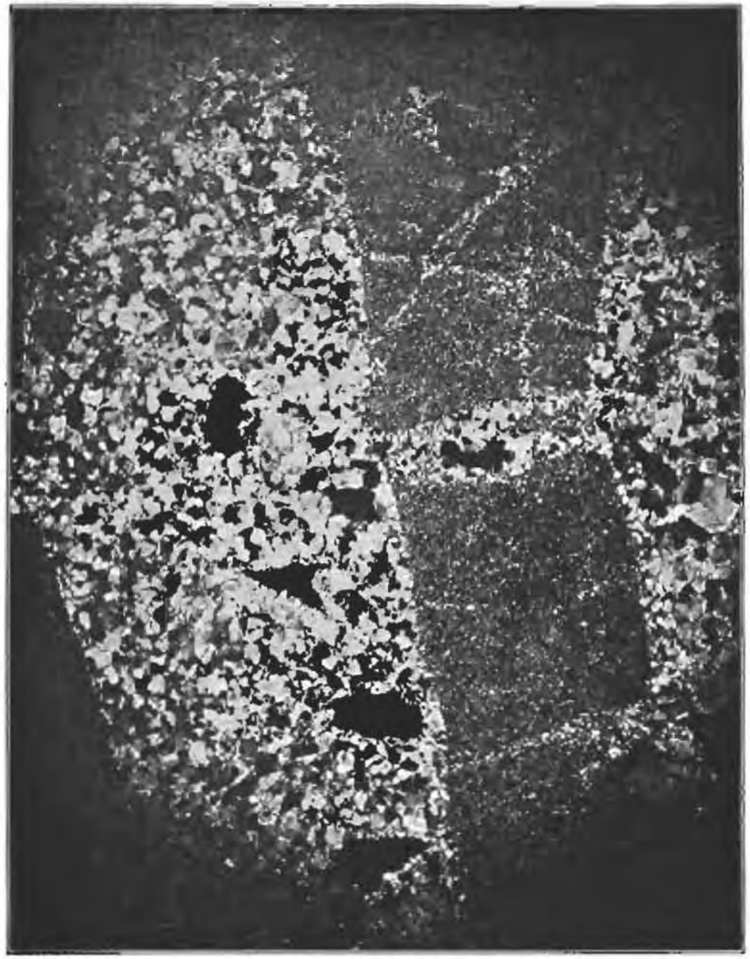
B. BANDED JASPEROID, SHOWING DIFFUSION BANDS, GEMINI MINE.

Light bands contain spherulites of chalcedony, dark bands microcrystalline quartz with pyrite, galena, and zinc blende; all three black. Magnified 25 diameters.

PHOTOMICROGRAPHS OF ORES.

A. FINE-GRAINED JASPEROID, BRECCIATED AND CEMENTED BY COLLOIDAL SILICA, LATER CRYSTALLIZED AS QUARTZ, EAGLE AND BLUE BELL MINE.

White areas are holes in section. Magnified 14 diameters.



B. SAME, WITH CROSSED NICOLS.

Black areas are holes in section. Magnified 14 diameters.

PHOTOMICROGRAPHS OF ORES.

quartz or fibrous quartz—that is, chalcedony. Heat accelerates the change to quartz.

The first stage of primary deposition, then, involves the replacement of limestone or dolomite by gelatinous silica, galena, and zinc blende. Subsequent crystallization of the colloid transformed it into chalcedony and more or less fibrous quartz.

The theory of replacement of limestone or dolomite by colloidal silica is not new, though it has not been advanced before in connection with ore deposits of this kind. A. H. Church [1] has shown experimentally that limestone may be replaced by colloidal silica. A solution containing silica was allowed to drop on a piece of recent coral; the calcium carbonate was replaced by silica; the replaced coral was covered with a thick film of gelatinous silica and was very soft. Much later H. F. Bain [2] suggested that the black chert of the Joplin district was formed by such replacement. This material is similar to the Tintic jasperoid, and some of it is banded in a similar manner. W. S. T. Smith,[3] however, showed later that this replacement proceeded in the normal way by the development of quartz crystals in the limestone.

SECOND PHASE OF MINERALIZATION.

GENERAL FEATURES.

The jasperoid is not everywhere a compact rock. In the ore shoots especially it contains abundant cavities of very irregular form or is shattered and brecciated (see Pls. XVIII, *A*, and XXIV, *A* and *B*, p. 161). In these openings were deposited the minerals of the second phase. They consist of barite plates, more abundant than in the first phase, and white or light-colored quartz, much of which projects into central vugs in crystallized form; the individual crystals are rarely more than 1 or 2 millimeters in length. Ore minerals were deposited with the gangue in large quantities, and the galena in particular takes the form of large crystals or grains.

Many of the cavities look as if they were caused by corrosion, and this is probably true in part. In places the quartz of this second phase seems to merge gradually into the earlier jasperoid. The effect is, in general, just that which might be produced by the contraction and crushing of a soft colloid material, such as the jasperoid is conceived to have been before it was finally recrystallized into quartz. In the banded jasperoid the cavities may cut across the banding or they may follow it, the bands being bent slightly to surround them.

Many cavities contain a third generation of barite plates coated and corroded by quartz.

The barite crystals of the second generation are in places large and abundant. That this mineral was the first to crystallize is shown by its partial replacement by quartz, the grains eating into the sides of the plates (Pl. XXIII, *A*). Around these partly corroded crystals the quartz is usually of somewhat differing grain, either coarser or finer than the rest.

The quartz filling in many specimens, particularly in those from the southern half of the sedimentary area, proves to be normal vein quartz of fine grain, allotriomorphic or hypidiomorphic, with sharp outlines and normal extinction. In such sections oblique light reveals depositional lines indicating the crystal form of quartz.

In the mines of the northern part of the sedimentary area more or less fibrous quartz and distinct chalcedony are associated with the granular quartz, and many veinlets in the jasperiod consist entirely of chalcedonic fibers. In transverse or oblique light the quartz filling of the second phase then shows delicate banding in rounded, mammillary form entirely similar to that of certain agates. (See Pls. XX–XXII.) Nowhere, except at the center of the vug, is there any indication of crystal form. The irregular outlines of the quartz grains, which may attain 0.3 millimeter in diameter, are shown to be entirely independent of the banding when observed between crossed nicols. Only here and there does a curved band of chalcedonic quartz follow the rounded outlines of the banding. (See Pl. XXI.) Such material is abundant in the Eureka Hill, Gemini, Chief, Eagle and Blue Bell, and Victoria mines but apparently not so common along the Iron Blossom line. In the Victoria and Grand Central both the crystalline and agate-like development of depositional lines were observed.

[1] On the composition, structure, and formation of beekite: Philos. Mag., 4th ser., vol. 23, p. 101, 1862.

[2] Preliminary report on the lead and zinc deposits of the Ozark region: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 106, 107, 1901. For a review of the whole subject see Siebenthal, C. E., Origin of the zinc and lead deposits of the Joplin region, Missouri, Kansas, and Oklahoma: U. S. Geol. Survey Bull. 606, pp. 181–183, 1915.

[3] Smith, W. S. T., and Siebenthal, C. E., U. S. Geol. Survey Geol. atlas, Joplin district folio (No. 148), p. 14, 1907.

and crystal faces of quartz are found lining the vugs in all mines.

In a specimen from the Victoria mine the whole mass is made up of an interlocking rather coarse quartz aggregate with veins of distinctly later crystalline quartz. The older quartz shows undulous and fibrous quartz throughout, and oblique light brings out a globular concentric texture as of a colloid deposit now changed to quartz. Similar specimens were obtained from the Grand Central mine.

In the Governor vein, south of the Iron Blossom, the replacement ore in the narrow vein consists of older fine-grained quartz and a younger generation of coarser quartz in which are embedded many corroded plates of barite. There is no indication of colloid deposition in this place.

The explanation is confidently advanced that the second phase of the primary mineralization consisted in the filling of the cavities of the silicified limestone or dolomite with crystalline barite and gelatinous silica, which shortly afterward was transformed into quartz and chalcedony. In places, however, where the temperature was higher, as in the southern part of the district, the filling was deposited directly as crystalline quartz. It is assumed, therefore, that the temperature during this phase was near the border of stability between colloid and crystallized silica, but that the colloid silica on the whole proved unstable.

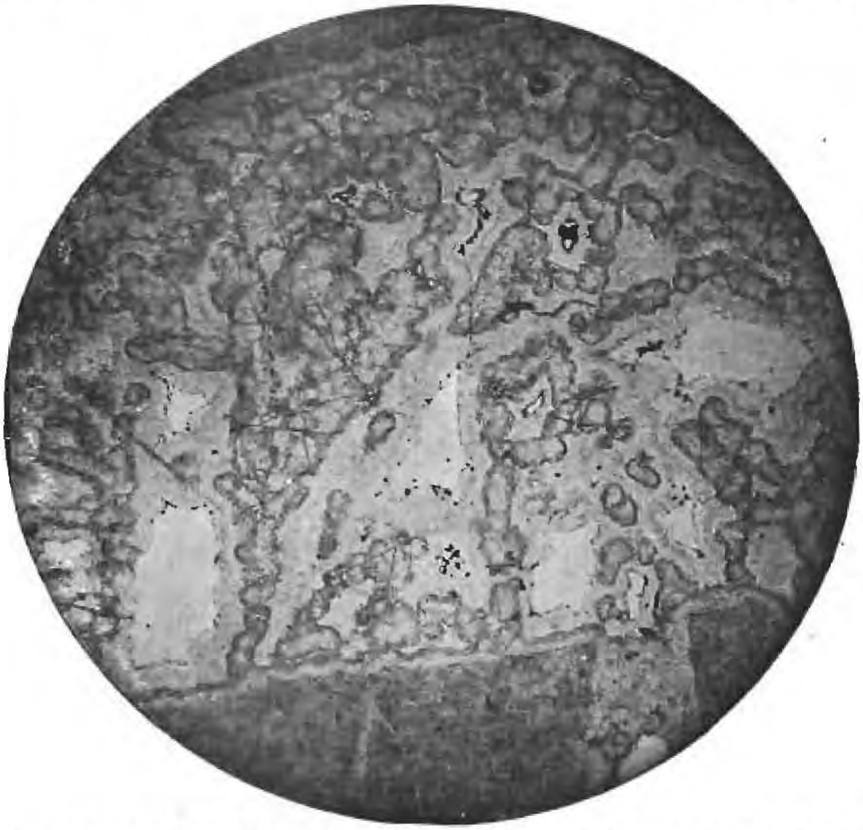
RELATIONS IN THE IRON BLOSSOM ZONE.

The relative quantities of the jasperoid and quartz of the second phase vary considerably. Among the northern mines the Chief Consolidated, Eagle and Blue Bell, and Victoria show large masses of jasperoid fractured and apparently corroded by white drusy quartz. Much of this material is a low grade ore with a few ounces of silver and 0.3 to 0.7 ounce of gold to the ton. One stope of this kind on the 1,200-foot level in the Victoria mine shows a solid mass of gray, delicately banded jasperoid in which there are many irregular veins and "solution cavities" of white quartz. In this place the white quartz is said to carry no silver or gold, and no sulphides are visible in either quartz or jasperoid.

On the other hand, in the deposits of the Iron Blossom zone the large masses of dark cherty jasperoid contain practically no metals and the ore bodies consist chiefly of the quartz of the second phase, except certain parts that are extremely rich in cerusite and residuary galena. Many of the bodies are 60 feet high and 50 to 100 feet wide and consist almost entirely of a loose cellular mass of quartz and barite, which changes near the margins to a dark brecciated jasperoid. The oxidation has of course contributed to this texture, but in large part it seems to be primary.

Thin sections of the dark jasperoid from the Beck Tunnel mine show as usual an interlocking aggregate of quartz with undulous extinction, the grains of which have a maximum diameter of 0.05 millimeter. Corroded barite prisms are embedded in this material. Irregular grains of cerusite and small hexagonal plates of plumbojarosite replace the quartz, which is cut by later veins of coarser quartz showing crystal outlines.

The cellular siliceous ore consists of more or less abundant thin plates of barite, many of them 10 millimeters or more in diameter. These are in part corroded and cemented by granular quartz with a diameter of grains ranging from 0.05 to 1 millimeter. This barite-quartz aggregate is also corroded and honeycombed, and in the holes are deposited quartz crusts of the third generation. In some specimens the barite is entirely dissolved, and a "hackly" texture results. There are no metallic minerals except some replacing cerusite and plumbojarosite. At some places the structure of the ore is dependent upon the arrangement of the cerusite in horizontal layers. The precise primary composition of this ore, so far as the metallic constituents are concerned, is somewhat difficult to ascertain. It probably contained very little pyrite, being made up chiefly of galena with a little zinc blende; its present content consists of a few per cent of lead and 20 ounces of silver (as horn silver) and \$5 to \$6 in gold to the ton. This ore occurs chiefly south of the Sioux-Ajax fault, where the deposit assumes the character of a vein; north of this fault in the great horizontal pipe (p. 136) the ore is considerably richer in galena and is probably a more direct product of replacement. It is difficult to interpret the ore bodies of Iron Blossom No. 1 as anything but a filling in a crushed and contracting mass of colloid silica.



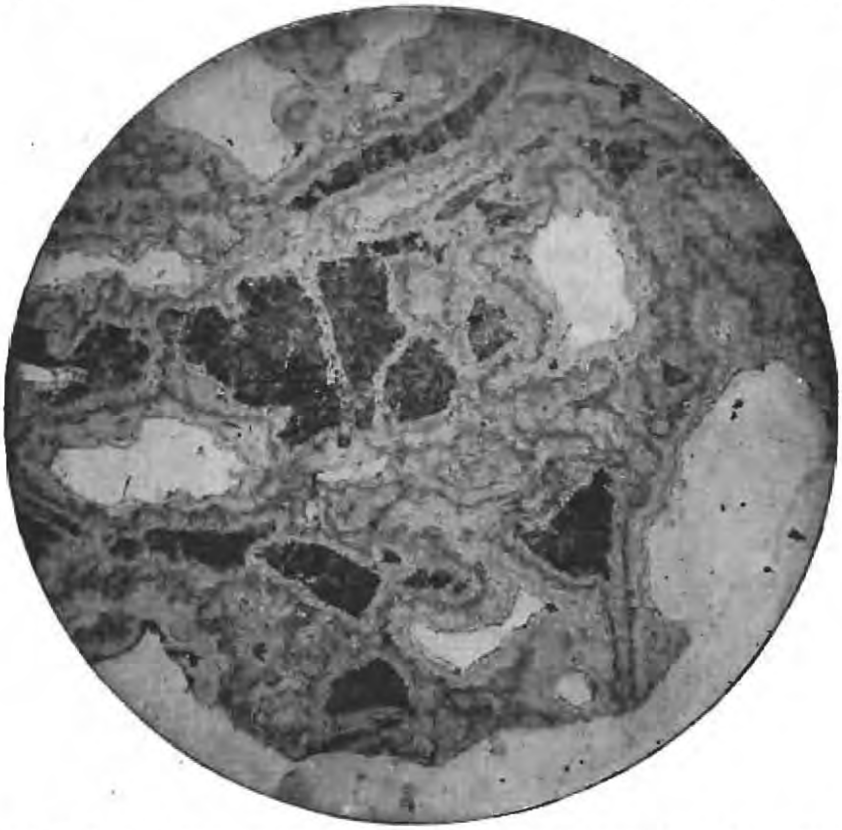
A. FINE-GRAINED JASPEROID, BRECCIATED AND CEMENTED BY COLLOIDAL SILICA; LATER CRYSTALLIZED TO QUARTZ, EAGLE AND BLUE BELL MINE.

White areas are holes in section. Magnified 25 diameters.

B. SAME, CROSSED NICOLS.

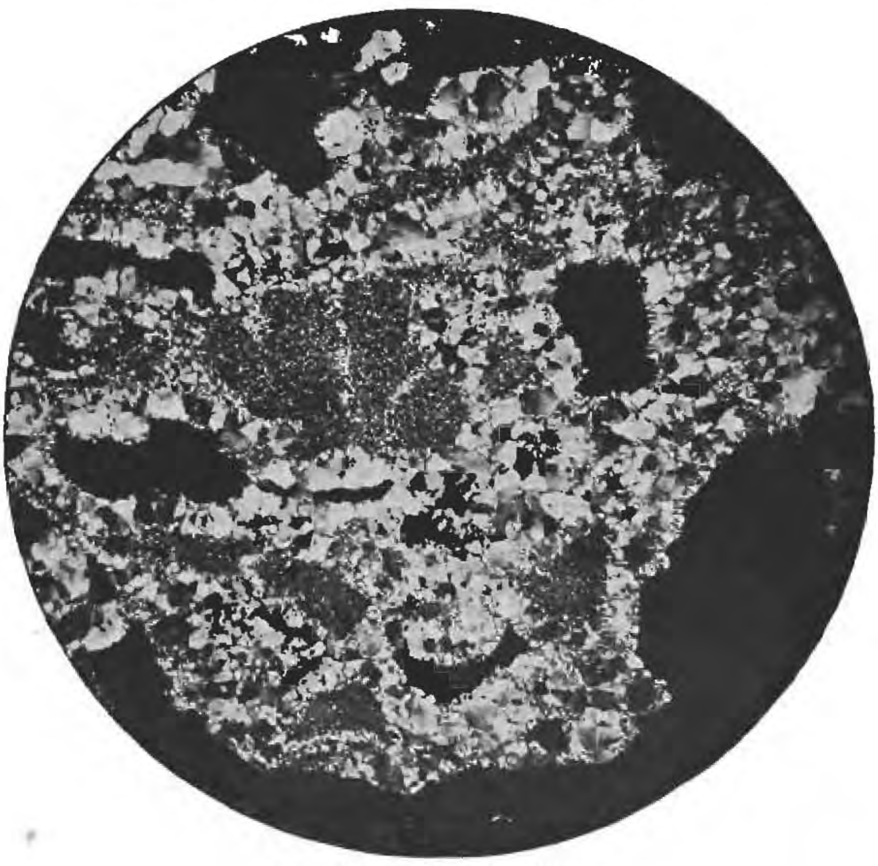
Black areas are holes in section. Magnified 25 diameters.

PHOTOMICROGRAPHS OF ORES.



A. INCLUSIONS OF FINE-GRAINED JASPEROID IN COLLOIDAL SILICA, LATER CRYSTALLIZED TO QUARTZ, EAGLE AND BLUE BELL MINE.

White areas are holes in section. Magnified 25 diameters.



B. SAME, CROSSED NICOLS.

Black areas are holes in section. Magnified 25 diameters.

PHOTOMICROGRAPHS OF ORES.

DEPOSITION OF DOLOMITE, CALCITE, AND ARAGONITE.

Calcium and magnesium carbonates are usually absent from the siliceous ores, except as rare residuary grains in the jasperoid.

A coarse granular dolomite or ankerite is associated with the ores in the Victoria and Eagle and Blue Bell mines.

In some of the outlying mines in the North Tintic and East Tintic districts galena is found in direct intergrowth with secondary dolomite or replacing limestone or dolomite. These occurrences are interpreted as nearly the last phase of mineralization at places where the depositing solutions have become weak and relatively cool. At these places the galena generally contains but little silver.

Calcite is present in two distinct forms—scalenohedrons or long pointed crystals, and flat rhombs, or disklike crystals. It also occurs in granular and columnar masses, but most of these masses that are adjacent to openings are terminated by one of the two crystal forms mentioned.

The scalenohedral calcite is only rarely noted within the siliceous ore bodies, where it is distinctly later than all the other primary minerals, including dolomite. Small veins or pockets of it have been found in the vicinity of the siliceous veins. It is more prominent in association with the nonsiliceous deposits in some of the outlying mines of the East Tintic and North Tintic districts. Here galena and zinc are found intergrown with granular or "sparry" dolomite and locally with scalenohedral calcite, having been formed by the replacement of limestone. The scalenohedral calcite in ore of this type is of later growth than the dolomite and is typically developed around cavities. The sulphides, however, continued locally to be deposited in small amount after the calcite had begun to form. Although thus intimately associated with nonsiliceous deposits, calcite is also found as strong barren veins in the North Tintic district a mile or more from any known body of ore. From these general relations the scalenohedral calcite is interpreted as the latest phase of primary mineral deposition.

Calcite in flat rhombohedrons is confined to the oxidized deposits. It has been found at several places perched upon primary scalenohedral calcite and also coats all the oxidized ore minerals with which it has been found in contact. It is clearly the latest of all the oxidation minerals, with the possible exception of aragonite and gypsum, both of which are too scarce for their paragenetic relations to be definitely known.

The cave deposits of secondary calcite have a fibrous or columnar structure. In some places their terminations are distinctly of the flat rhombohedron habit; in other places they are bluntly pointed as in the unit rhombohedron. These deposits as a rule are not closely associated with the oxidized ores.

Aragonite in delicate needles has been observed at many places also as one of the very latest oxidation minerals but not in direct intergrowth with secondary ore minerals. In the cave of the Iron Blossom No. 3 mine tufts of aragonite needles were found grown upon the surface of the calcite crust, and this aragonite was certainly of later deposition than the calcite. One specimen of aragonite associated with oxidized zinc ores in the Gemini mine was found by qualitative test to contain a little zinc. As this specimen was not found in place, its paragenetic relations are not known.

DEPOSITION OF ORE MINERALS.

GENERAL FEATURES.

From the above discussion it is apparent that ore minerals were deposited during the whole range of mineralization. The typical jasperoid may contain small grains of pyrite, galena, zinc blende, and enargite, though the pyrite is generally present in small amounts. During the second phase of silicification ore minerals were deposited in abundance in larger individuals and in repeated succession. The grains are commonly of large size, except those of pyrite. The galena occurs in large grains and imperfect crystals or coarse aggregates, replacing the jasperoid or developing with quartz in open cavities. Enargite mostly takes the form of more or less perfect isolated crystals which replace jasperoid (Pl. XXIII, *B*, p. 160) and many of which contain small grains of pyrite and chalcopyrite. Tetrahedrite and famatinite are intergrown with enargite. Zinc blende is rarely found in large masses but is usually contained as small grains in galena. The ore minerals in the druses of

the second phase of silicification occur in several generations; they are found at the bases of the druses covered by quartz and barite, or they may cover the quartz and project as small crystals into the cavity, or they may occur in the quartz-barite mass, where many of them are formed by replacement.

The galena carries its silver in the form of argentite. If galena that contains any considerable amount of silver, say above 20 ounces to the ton, is etched with dilute nitric acid the irregularly distributed grains of argentite are usually brought out (Pl. XXIX, *D*, p. 169). Such argentite is certainly primary, but in places rims of the same mineral edge the galena in the oxidizing ore, and these may be secondary.

The secondary sulphides, chalcocite, covellite, geocronite, proustite, and argentite are discussed under "Oxidation" (p. 163).

CLASSIFICATION OF ORES.

The ores vary greatly in appearance and composition, and the ever present oxidation makes it difficult to arrive at a reliable conclusion as to exact character of some of the primary ore. Transitions of many kinds are found, but the primary ores may be roughly classified as follows:

Heavy lead ores. These contain, besides galena, a little pyrite, zinc blende, and more rarely tetrahedrite; also as much as 50 ounces of silver to the ton, but very little or no gold. The nonsiliceous galena-cerusite ores in a few of the mines, especially in the outlying districts, are low in silver.

Siliceous lead ores. These contain scattered galena in a siliceous gangue with minor amounts of zinc blende, pyrite, and in places tetrahedrite. The silver content is variable, locally high.

Siliceous gold-silver ores. These are generally of low grade, carrying a few dollars in gold and 20 ounces or less of silver to the ton, and in many places they contain no recognizable metallic minerals except some cerusite and copper stain. Their texture is generally drusy and honeycombed, but here and there, as in the Victoria mine, they may consist of massive jasperoid.

Heavy copper ores. These contain much enargite and minor quantities of pyrite and chalcopyrite in a gangue of silica with much barite. They yield usually about 20 ounces of silver and at most $12 in gold to the ton. They are not abundant.

Siliceous copper ores. These are common in the southern part of the district and contain the same minerals as the heavy copper ores, with perhaps 10 ounces of silver and $5 in gold to the ton.

Siliceous lead-copper ores. These mixed ores are generally found along the line where the lead ores give place to copper ores, as in the Eureka Hill and Grand Central mines.

The rich gold ore and silver ores, as well as the zinc ores, are produced by processes of oxidation.

SUCCESSION OF MINERALS.

No single rule can be given for the succession, because there are several generations of the minerals. In any one series the barite is followed by quartz; then comes pyrite, which is usually the oldest of the metallic minerals and is followed by enargite, tetrahedrite, and famatinite, deposited simultaneously; galena and zinc blende are generally later, and in some ores zinc blende clearly replaces galena. All the ore minerals may replace quartz and, less easily, barite.

GOLD AND SILVER IN ORE MINERALS.

The galena carries the larger part of the primary silver, as argentite (Pl. XXIX, *D*, p. 169). Generally the silver content varies from 10 to 60 ounces to the ton. There is reason to believe that the tetrahedrite also contains a fair amount of silver, though no assay has been made because the mineral occurs in very small grains. The enargite carries only a moderate amount of silver but always contains some gold. A specimen of pure enargite from the Gemini mine was found to contain $1.65 in gold and 45.5 ounces of silver to the ton. Another specimen, from the Victoria mine, contained $8 in gold and 47.1 ounces of silver to the ton. Pyrite from the Centennial Eureka mine is said by the mine officers to contain 0.1 ounce of gold and 2 to 3 ounces of silver to the ton. Some pyrite in the Swansea mine contains considerable silver but very little gold.

OXIDATION OF THE DEPOSITS.

GENERAL FEATURES.

The Tintic district is remarkable for an unusually low water level and corresponding great depth of oxidation. Within the sedimentary rocks this depth is at least 1,600 feet, and the Mammoth workings (p. 214) have attained 2,300 feet without finding the water level.

In most places the oxidation is not complete. Generally enough of the primary sulphides remain to allow a conclusion as to the primary character of the ore, and such remnants are found at all levels from the surface down to the water level. There has also been a great deal of migration of minerals which has resulted in the forming of shoots of certain ore minerals,

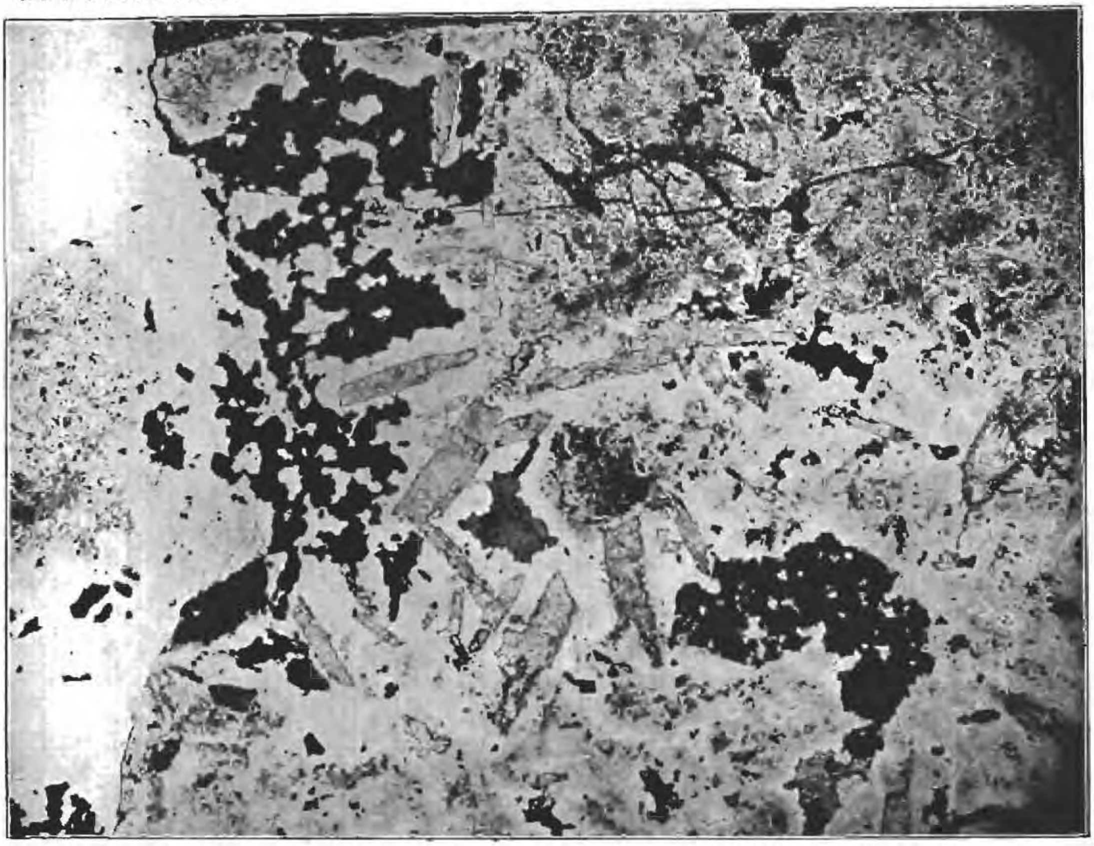
A. BARITE PLATES OF SECOND PHASE, IN CROSS SECTION, PARTLY REPLACED BY QUARTZ OF SAME PHASE, GOLD CHAIN MINE.

Magnified 25 diameters.

B. ENARGITE CRYSTALS REPLACING JASPEROID OF FIRST PHASE, PARTLY REPLACED BY OLIVENITE, MAMMOTH MINE.

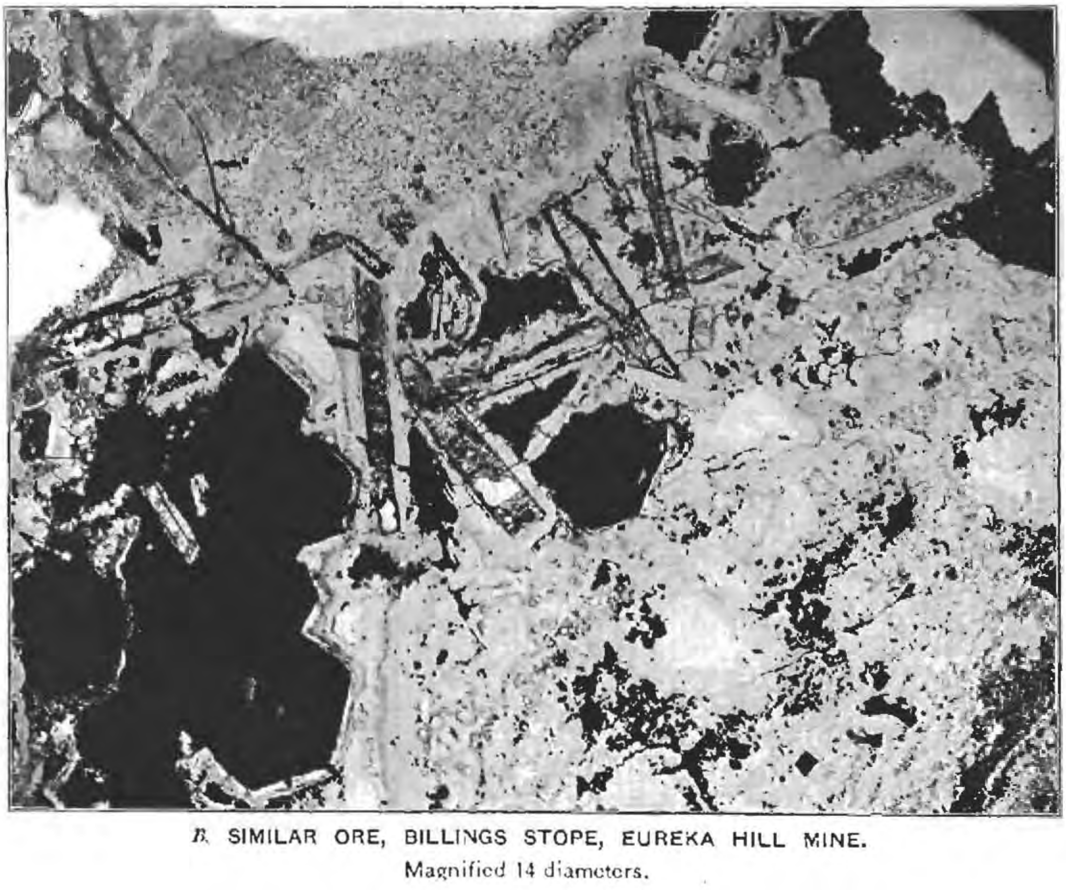
Magnified 25 diameters.

PHOTOMICROGRAPHS OF ORES.



A. GALENA, BARITE, AND QUARTZ, ALL OF SECOND PHASE, WITH ILL-DEFINED FRAGMENTS OF OLDER JASPEROID CONTAINING PYRITE, GALENA, AND TETRAHEDRITE, GEMINI MINE.

Quartz is microcrystalline but shows mammillary deposition lines of colloid silica. Magnified 14 diameters.



B. SIMILAR ORE, BILLINGS STOPE, EUREKA HILL MINE.

Magnified 14 diameters.

PHOTOMICROGRAPHS OF ORES.

but this migration has not been carried very far and there are no well-defined vertical zones of enrichment. Copper and silver sulphides as well as native gold have been segregated into separate shoots in places, but there is no definite zone of sulphide enrichment unless the ore of the Gem channel, in the Gemini mine, should prove to be of this type.

The character of the oxidation has been influenced by the relative scarcity of pyrite, the presence of much calcium carbonate in the waters and wall rock, and the abundant formation of difficultly soluble products such as cerusite, anglesite, and copper arsenates.

The oxidized products generally replace the jasperoid and the quartz; this results in a drusy and honeycombed texture. They also, particularly the zinc minerals and to a less degree malachite and azurite, replace the surrounding limestone.

During the oxidation the solutions were subject to many changes in character. Although in general quartz is dissolved, there is ample evidence that quartz was also deposited in places, though this secondary quartz is much less abundant than that of the primary mineralization. Quartz in crusts of small crystals, for instance, covers chrysocolla and limonite in some specimens.

In general, then, the ores are oxidized to anglesite, cerusite, plumbojarosite, lead oxychlorides, smithsonite, hydrozincite, calamine, arsenates of copper, bismuth, and zinc, copper carbonates, jarosite, other iron sulphates, cerargyrite, native silver, and native copper. Other minerals are kaolin, alunite, gypsum, limonite, and oxides of manganese. The list of oxidized minerals of the Tintic district is unusually long.

The lead ores yield only a moderate amount of limonite, but some of the oxidized copper ores contain 15 to 20 per cent. Iron is in part carried into the adjacent limestone by sulphate solutions and deposited as limonite by replacement, or it forms stalactites in caves. Stalactites of this kind in the Ajax mine are described in the earlier report.[1] The limonite was apparently deposited on older crystals of gypsum. A similar occurrence in the Iron Blossom No. 1 mine (p. 243) has been called to the writer's attention by Mr. M. L. Crandall, jr. The cave in this mine, besides containing limonite stalactites with casts of gypsum, also revealed large masses of gypsum on its bottom, which formed an interlacing mass of crystals as much as 17 inches long. In many of these caves residuary masses of oxidized lead and copper ores were found. Most of the caves are caused by the contraction of volume due to oxidation of the ore and by the subsequent settling of the limestone.

OXIDATION BELOW WATER LEVEL.

Developments for 250 feet below water level in the Gemini mine have shown that partial oxidation continues to that depth; limonite, cerusite, native silver, and copper arsenates have been found down to that depth. In most mines, however, the quantity of unoxidized galena gradually increases from a point 600 or 800 feet below the surface.

TEXTURE AND STRUCTURE OF OXIDIZED ORE.

In the oxidized ores cavernous and cellular textures are very common, owing to the general solution and replacement of quartz. Brecciated forms are frequently found (Pl. XXV, *B*, p. 162), and in places banded structure occurs, as in the specimen illustrated in Plate XXV, *A*, which shows what is apparently diffusion banding of malachite and brown copper pitch ore.

OXIDATION OF LEAD ORES.

The oxidation of galena normally results in the following successive products: (1) Anglesite, (2) cerusite, (3) plumbojarosite and mixed sulphates; also oxychlorides. Oxidation to mimetite and pyromorphite has been observed in the Eureka Hill mine.

The galena first always alters to a dark fine-grained anglesite colored by minute residual masses of galena (Pl. XXVI, p. 166). This change begins along the cleavage lines and proceeds until the entire sulphide is altered. During this process some galena is evidently recrystallized which during subsequent alteration is finally oxidized. The galena usually contains some primary zinc blende, but this is evidently wholly converted to soluble sulphate. If copper is present some of it may be converted to chalcocite and covellite, which are contained in the anglesite along the contact or may surround grains of residuary galena in the anglesite.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 746.

This process is accompanied by a recrystallization of the coarsely crystalline galena to the fine-grained variety "steel galena," which so far as observed is found only along the narrow transition zone adjoining the anglesite.

The dark, in places concentrically banded anglesite is soon converted into massive cerusite, and the cerusite is covered and corroded by yellowish crusts of plumbojarosite and allied minerals. These may again be covered by white crystal tufts of a second generation of cerusite.

In some places the anglesite instead of forming concentric crusts is deposited as perfect crystals in vugs in the galena ore. Fine examples of this mode of occurrence were observed in the Eureka Hill and Chief mines.

At many places the jasperoid and quartz are abundantly replaced by hexagonal yellow crystals of plumbojarosite and by irregular grains of cerusite and less commonly anglesite.

The powdery yellow decomposition products that replace the cerusite were carefully examined. In many of them jarosite or plumbojarosite could be detected and some are rich in bismite or bismutite. The following samples of such material were examined and analyzed by R. C. Wells in the laboratory of the Survey:

Partial analyses of soft yellow lead ores from Tintic district.

[R. C. Wells, analyst.]

	1	249	272	275a	275b	278
Loss on ignition	4.94	5.03	2.62	8.39	....	3.55
Insoluble in HNO_3 (mostly silica and barite)	82.96	81.83	59.87	....	....	82.15
Soluble in HNO_3:						
CO_2	.22	.71	2.15	14.43	....	.27
Cl	Trace.	Trace.	None.	.02	1.15	None.
As_2O_5	Trace.	1.68	2.16	....	....	Trace.
P_2O_5	.41	None.	None.	....	....	None.
Cu	Trace.	None.	Trace.	....	....	None.
Ag	.29	None.	1.44	....	.33	None.
PbO	.58	3.26	12.25	72.85	16.48	4.04
Fe_2O_3	8.24	2.72	1.72	.58	12.48	.40
CaO	.20	.44	1.26	None.	....	.22
MgO	None.	None.	None.	None.	....	None.
Bi_2O_3	Trace.	2.50	9.07	....	....	None.
SO_3	.58	(?).95	.41	1.19	3.83	None.
	98.42	99.12	92.95	97.46	....	90.63

1. Gemini mine, yellow oxidized ore, level 19, Gem channel. Hot water extracts traces of chlorine, lead, and calcium. Ammonium acetate extracts considerable lead sulphate.

249. Eagle and Blue Bell mine, north end, winze from 1,200-foot level. Ammonium acetate extracts a little lead sulphate. Dilute nitric acid extracts a trace of chlorine and considerable lead.

272. Eagle and Blue Bell mine, same locality. Quartzose ore. Hot water extracts a trace of chlorine but no lead.

275a. Colorado mine, close to Sioux line.

275b. Same locality. Yellow powder on cerusite.

278. Colorado mine, Hornsilver stopes. Hot water extracts a trace of chlorine and lead, some calcium, and sulphates.

Samples 249 and 272 contain minute hexagonal crystals of what is probably plumbojarosite. The results show that these yellow substances are of variable composition. Lead chloride seems to be present in traces in samples 1 and 278, and in somewhat larger amounts in sample 275. In sample 275b after subtracting the chlorine necessary for silver chloride there remains about 1 per cent of chlorine for lead oxychloride.

Sample 1 contains argentite, limonite, anglesite, calcite, some iron sulphate and phosphates, and possibly also silver chloride in the insoluble part. The other samples show practically no phosphorus.

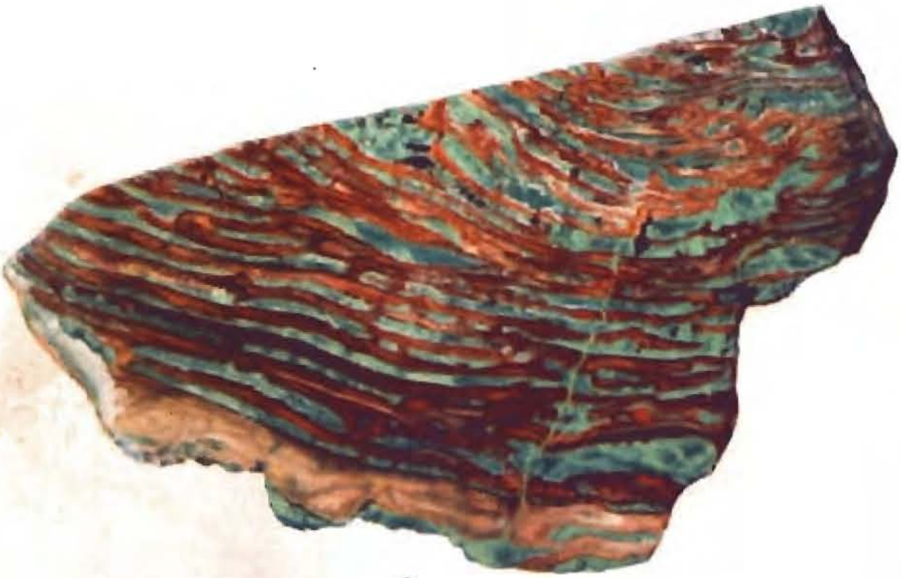
In sample 249 there is a little anglesite, much more cerusite, jarosite or plumbojarosite, bismite, and probably an iron or bismuth arsenate, but no silver.

Sample 272 contains nearly 2 per cent of argentite, about 14 per cent of cerusite, jarosite, and probably a bismuth arsenate and bismite.

Sample 278 contains no silver in the part soluble in nitric acid; there is probably some cerusite, but the analysis leads to the inference that minium or massicot (lead oxides) is present.

During the replacement of galena to anglesite and cerusite there has been compara-

A.



B.

SECONDARY COPPER ORES.

A. Brecciated ore, Ajax mine. Shows concentric deposition of malachite, chrysocolla, and brown "copper pitch ore." Later brecciated with jasperoid and cemented by calcite (white).

B. Banded ore, Ajax mine. Shows probable diffusion banding of malachite and brown "copper pitch ore."

tively little migration, though in some of the granular quartz rocks cerusite in small grains is widely distributed and directly replaces the quartz.

More extensive migration evidently took place during the second phase of oxidation, when cerusite was attacked by solutions containing sulphuric acid and chloride of sodium. Both plumbojarosite and lead chlorides may have migrated for considerable distances, though not to compare with the wanderings of copper and zinc, and it is possible that some of the low-grade siliceous lead ores derived their metal in this manner.

SECONDARY GEOCRONITE.

A specimen from the Colorado mine (No. 277), investigated by Messrs. Means and Whitehead, proved particularly interesting. It shows massive galena going over to "steel galena" and thence into anglesite and cerusite. About half an inch from the contact the galena upon etching with hydrochloric acid was shown to contain feathery aggregates of a mineral not attacked by the acid (Pl. XXIX, *E*, p. 169). Enough of this mixture was isolated for a qualitative analysis. R. C. Wells reported that it contained, in addition to lead and sulphur, much antimony, a little zinc (about 1.6 per cent), and arsenic, but no copper or iron. Under high magnification in polished section the galena is seen to be filled along the cleavage faces by narrow lines of this resistant mineral gradually spreading into feathery masses and irregular veinlets. The galena also contains a few grains of zinc blende, which apparently is contemporaneous with it. Near the oxidized contact the galena is filled both with anglesite and the mineral under discussion. This mineral reacted as follows: HCl (concentrated), instantly bright brown, then iridescent; HNO_3, effervesces slightly, blackens with white coating; KOH and KCN, no reaction. According to Murdoch's tables [1] this corresponds to geocronite ($5PbS.Sb_2S_3$); such a mineral with much lead and little antimony would in fact be expected as the result of the replacement of galena in a deposit where little antimony was available.

In one specimen from the Eagle and Blue Bell mine veinlets of geocronite were found cutting across a vein of anglesite in the galena, and grains of anglesite are included in geocronite. It was therefore concluded that the geocronite was formed during the same period as the anglesite, which continued to develop after the geocronite had ceased to replace the galena. The anglesite of this specimen is partly replaced by chalcocite and covellite. The general succession of minerals in this specimen is as follows: Primary, pyrite, quartz, zinc blende, galena; secondary, geocronite and anglesite, chalcocite, covellite, cerusite. (See fig. 19, p. 147.)

[1] Murdoch, Joseph, Microscopical determination of the opaque minerals, New York, 1916.

OXIDATION OF COPPER ORES.

GENERAL FEATURES.

The oxidized copper ores consist generally of a matrix of jasperoid or fine-grained siliceous rock with or without barite. This is usually more or less cellular and honeycombed, the cavities being coated with minute quartz crystals and filled with oxidized copper minerals. The copper arsenates commonly also replace the quartz. Residuary enargite is common in all ores and may contain a little pyrite and chalcopyrite or appear mixed with famatinite. Small pyrite crystals are scattered through much of the jasperoid; some have escaped oxidation, but others are indicated only by pseudomorphs of limonite. The ores rarely contain very much limonite, those of the Centennial Eureka, which carry about 17 per cent of iron, showing the maximum. Secondary quartz in crusts on limonite or chrysocolla is rare on the whole, and the latest products sonsist of a few flat rhombohedrons of calcite.

Residuary enargite is present at all levels. It is said, however, that in the Centennial Eureka there was little enargite above level 10.

In the district regarded as a whole there is no indication of richer copper ores at any certain depth below the surface. The bodies of the Centennial Eureka, which are the largest in Tintic, contained the richest copper ores below level 7. Possibly there has been at this locality some concentration by descending waters, but it is not strongly enough marked to establish the presence of definite enriched zones. Local migration and enrichment are common. In the same mine barite occurs in increasing quantities with increasing depth, but this also is probably not a general rule.

GENERAL COURSE OF OXIDATION OF ENARGITE.

It is generally known that enargite is one of the minerals most resistant to oxidation. Its presence seems to some extent to protect the pyrite, which is preserved in many places where one would expect it to have been oxidized. The oxidation of enargite requires a large amount of oxygen; however, it would doubtless be more complete in the Tintic district were it not for the fact that all the mine waters contain much carbonate of calcium, which speedily neutralizes the free sulphuric acid and results in the formation of soluble sulphate of calcium.

Frequently the action begins by the simultaneous development of chalcocite, covellite, and arsenates; the two secondary sulphates then generally replace the margin of the enargite (or famatinite), and the arsenates move out on fissures or replace quartz; in places they are mixed with strings of chalcocite. (See fig. 18, p. 144.)

The schematic course is represented by the following formula:

$$\underset{\text{enargite}}{2Cu_3AsS_4} + 30O + H_2O + 7CaCO_3 =$$
$$\underset{\text{olivenite}}{(CuO)_4.As_2O_5.H_2O} + \underset{\text{chalcocite}}{Cu_2S} + 7CaSO_4 + 7CO_2$$

If oxidation is carried to its conclusion the secondary chalcocite turns into covellite and this into copper sulphate solutions.

The arsenates of copper are insoluble salts that are but little subject to migration. If bismuth is present (probably in the form of an unknown sulpharsenide) arsenates of bismuth will form. Antimony in famatinite and tetrahedrite must also go into oxidized compounds, but so far none of these compounds have been discovered; neither antimonates nor antimony oxides have been identified. Antimony, however, is present only in small quantities. There is only a little zinc sulphide in the copper ores, and it oxidizes after the normal course.

The newly formed arsenates either replace enargite crystals with perfect retention of outlines, or replace jasperoid and quartz, or fill fissures, or crystallize in vugs, forming beautiful small druses. In general, the olive-colored olivenite, containing only 3.2 per cent of water, is the first copper arsenate to form, and this is followed by lustrous bluish-green clinoclasite with curved crystal faces, by mammillary dull-green erinite, and by pearly scales of pale blue-green tyrolite, which contains 17 per cent of water. The characteristic conichalcite, an arsenate of calcium and copper carrying 5.52 per cent of water, is distinctly later and evidently results from the action of a strong calcium carbonate solution. It is often found without sulphides, and without other arsenates, its small but conspicuous yellowish-green spherical concretions dotting the honeycombed jasperoid. Chrysocolla appears in places without any well-defined rank; malachite and less commonly azurite are fairly abundant, especially near the walls of the deposits, where they may surround residual masses of limestone. On the whole, olivenite and conichalcite are the most common of the copper arsenates.

Of iron arsenates, the brown cubes of pharmacosiderite are most abundant, associated with the later copper arsenates. White earthy aluminum sulphates more or less definitely recognizable as alunite are among the last products, in places capping azurite or malachite. Cuprite and native copper are not abundant; they seem to be later than the copper carbonates.

There are many exceptions to the succession just outlined. A number of specimens were studied by Mr. W. L. Whitehead, with a view to ascertaining the paragenesis, and the writer, through the kindness of Prof. Charles Palache, also examined specimens from the Holden collection at Harvard. A few of these successions are given below, the older minerals being named before the younger.

Mammoth outcrop.

1. Quartz, enargite, famatinite.
2. Olivenite, azurite, pharmacosiderite.
3. Clinoclasite, tyrolite.

Ajax dump.

1. Barite, quartz, enargite.
2. Conichalcite, scorodite.
3. Malachite.
4. Chrysocolla.
5. Alunite.
6. Limonite and calcite.

Victoria.

1. Quartz, enargite.
2. Enargite.
3. Tyrolite.
4. Conichalcite.
5. Alunite, malachite, chrysocolla.
6. Limonite.

Centennial Eureka.

1. Quartz, enargite, chalcopyrite.
2. Olivenite.
3. Malachite, chrysocolla.
4. Alunite and chalcanthite.

Gold Chain.

1. Barite, quartz, enargite.
2. Olivenite, erinite, conichalcite.
3. Tyrolite, malachite, azurite, chrysocolla.
4. Alunite.

Black Jack dump.

1. Quartz, barite.
2. Conichalcite, quartz.
3. Scorodite.
4. Jarosite.

Centennial Eureka.

1. Quartz.
2. Olivenite.
3. Azurite and malachite.
4. Conichalcite.
5. Tyrolite.

Victoria.

1. Quartz, enargite.
2. Olivenite.
3. Conichalcite, malachite, azurite, and erinite.

Grand Central.

1. Quartz.
2. Olivenite.
3. Conichalcite.
4. Malachite, chalcanthite.

Eureka Hill.

1. Quartz, enargite, tetrahedrite, galena.
2. Anglesite, covellite.
3. Cerusite.

In a few specimens malachite and clinoclasite are earlier than olivenite. Pharmacosiderite may be earlier or later than malachite. It is possible, of course, that a mineral may belong to two or more generations: Olivenite, for instance, has certainly crystallized at various times. There is not much information about the tenor of the pure arsenates in gold and silver. Some of them, as well as the cuprite and malachite, are very poor, but wherever chalcocite is present a concentration of silver seems to have taken place.

CHALCOCITE AND COVELLITE.

One definite fact ascertained during the present examination is that covellite and chalcocite occur everywhere and at all levels in the copper ores of the oxidized zone, though nowhere in great masses. They are not remains of an older zone of secondary sulphides but form normally during oxidation. This condition, which is contrary to the generalized idea of a distinct zone of secondary copper sulphides, is no doubt due in part to the scarcity of pyrite, to the neutralization by $CaCO_3$ of such acid as may be formed, and in part also to the great amount of oxygen necessary for the complete oxidation of enargite. There can be no question, however, that secondary sulphides may form freely in other deposits, under certain conditions, in the zone accessible to oxygen.

The manner of oxidation of enargite, with simultaneous development of chalcocite, covellite, and copper arsenates, is described on page 164. In the specimens chalcocite and covellite usually form dark sooty or dull-bluish spots in or near the partly oxidized enargite, and covellite often crystallizes together with anglesite in the druses. A close association of covellite and anglesite is, in fact, very common and is seen in specimens, thin sections, and polished sections. Covellite frequently replaces galena and zinc blende, but its most common occurrence is in enargite, famatinite, tetrahedrite, and pearceite. All these relations are, of course, best studied under the metallographic microscope.

During the oxidation of enargite and similar minerals chalcocite is always the first mineral to form along the margins and fissures in the grain. Plate XXVII, *A*, *B*, *C*, and *D*, shows how, besides the marginal chalcocite and covellite in the enargite, bands and streaks of those minerals, delicately folded and faulted, develop in the veinlets of olivenite or other arsenates. Chalcocite rarely shows the normal white color in reflected light but is usually bluish gray; this color is caused by an almost submicroscopic intergrowth with covellite. Subsequently larger blades of normal covellite were developed in this mass.

It has not proved possible to obtain enough of these secondary sulphides in pure form for assay, but it is stated that where they are abundant they generally contain much silver. No gold seems to be associated with them. No bornite has been found.

Secondary copper sulphides thus form independently of the water level—in fact, at all points above it and at least to a depth of 250 feet below it, as shown by the development of covellite in pearceite in ore from level 19 in the Gemini mine.

PLATE XXVI.

A. Anglesite (gray) with residuary galena (white) in part recrystallized in veinlets, Colorado mine. Magnified 100 diameters.

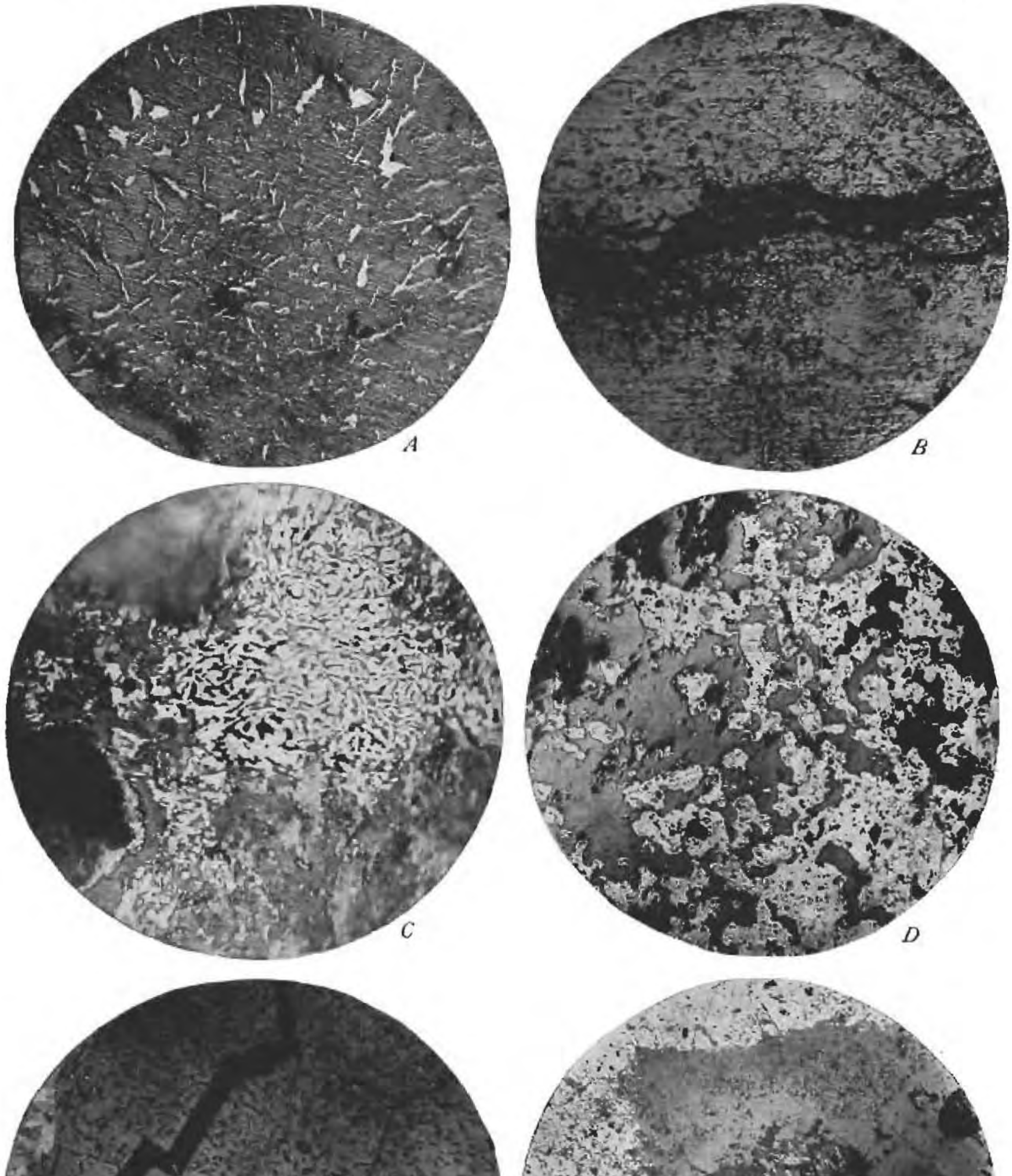
B. Galena (gray) altering to anglesite (black), Colorado mine. Magnified 100 diameters.

C. Covellite (dark gray) replacing galena (white), Gem channel, nineteenth level, Gemini mine. Magnified 1,000 diameters.

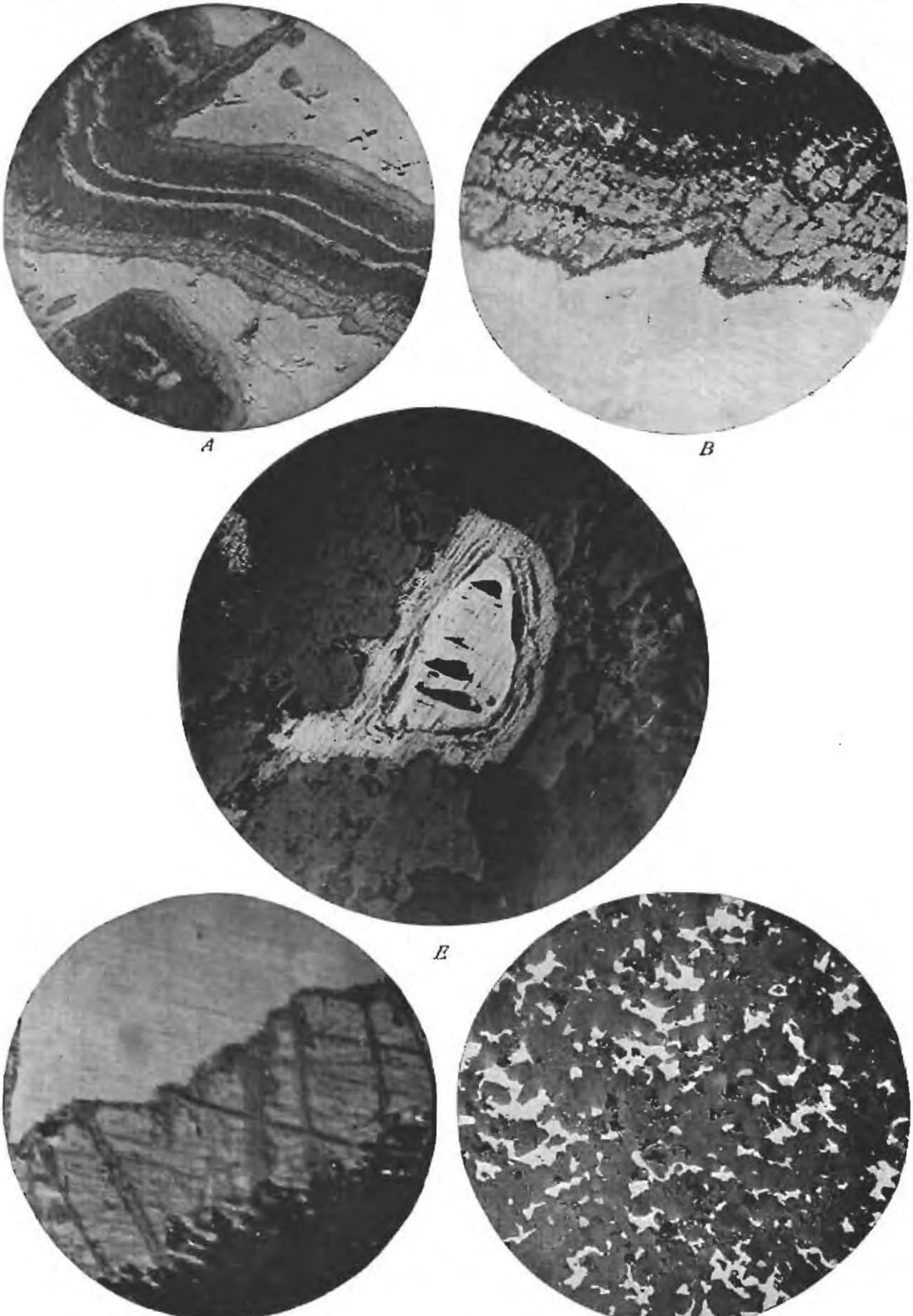
D. Zinc blende (gray), probably contemporaneous with galena (white), Colorado mine. Magnified 100 diameters.

E. Anglesite developing in veins and along cleavage of galena, Colorado mine; argentite (dark gray) and galena (light gray). Magnified 100 diameters.

F. Covellite in center (black) intimately associated with chalcocite (grayish white), surrounded by anglesite, Colorado mine; galena beginning to be converted to anglesite appears at the periphery. Magnified 100 diameters.



PHOTOMICROGRAPHS OF ORES.



PHOTOMICROGRAPHS OF ORES.

PLATE XXVII.

A. Chalcocite (dark gray) and copper arsenates (black) developing in enargite (light gray), 1,050-foot level of Victoria mine. Magnified 360 diameters.

B. Copper arsenates (black) and chalcocite (dark gray) in enargite (light gray), showing alteration rim of latter, 1,050-foot level of Victoria mine. Magnified 1,000 diameters.

C. Similar alteration rim as in *B*. Copper arsenates (black) and enargite (light gray); transition rim of gray chalcocite traversed by plates of covellite; 1,050-foot level of Victoria mine. Magnified 2,000 diameters.

D. Copper arsenates (dark gray) intergrown with chalcocite and of simultaneous origin, 700-foot level, Butterfly stope, Grand Central mine. Magnified 480 diameters.

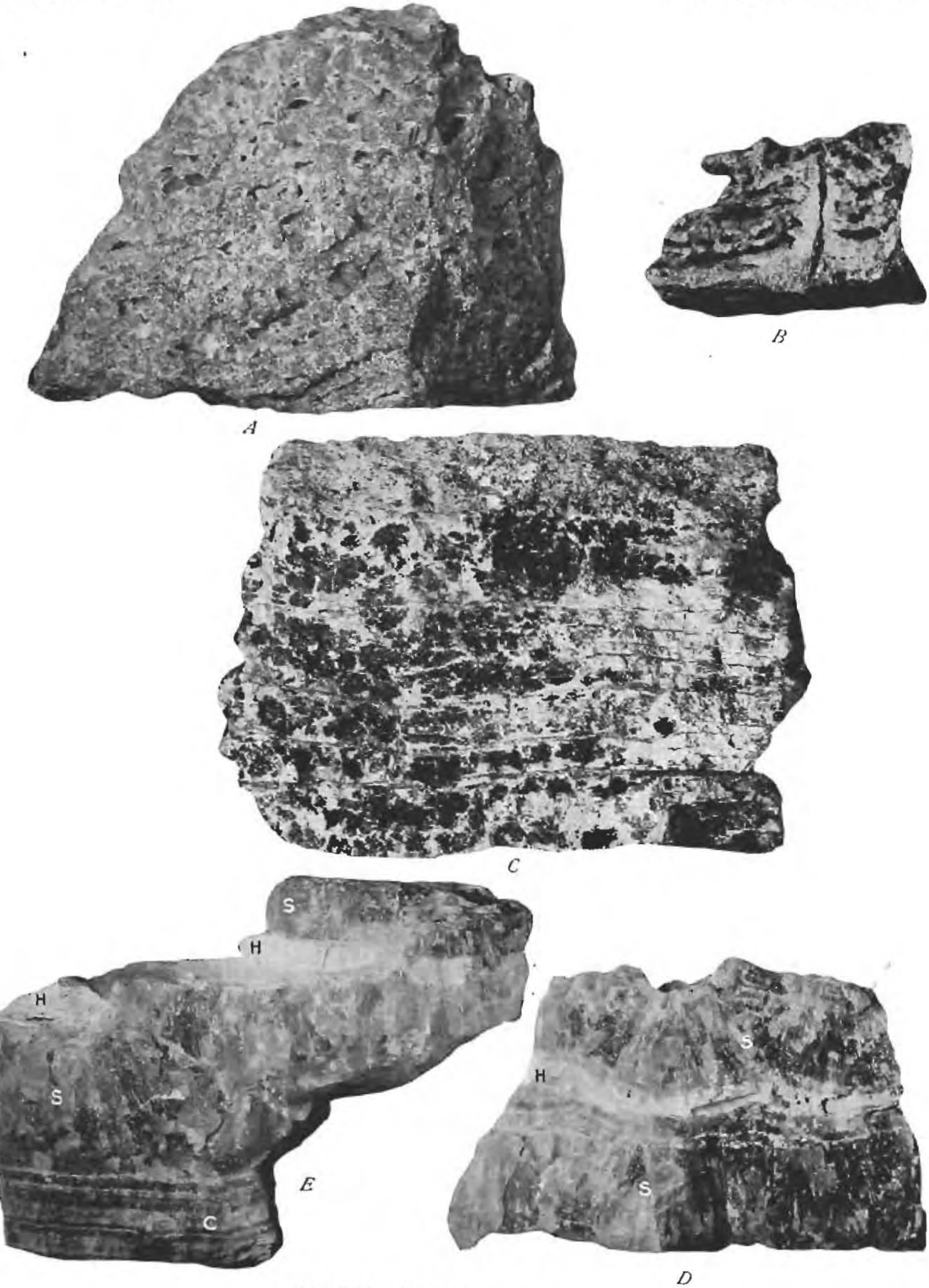
E. Argentite in concentric deposition surrounding proustite; in siliceous gangue, Chief Consolidated mine. Magnified 100 diameters.

PLATE XXVIII.

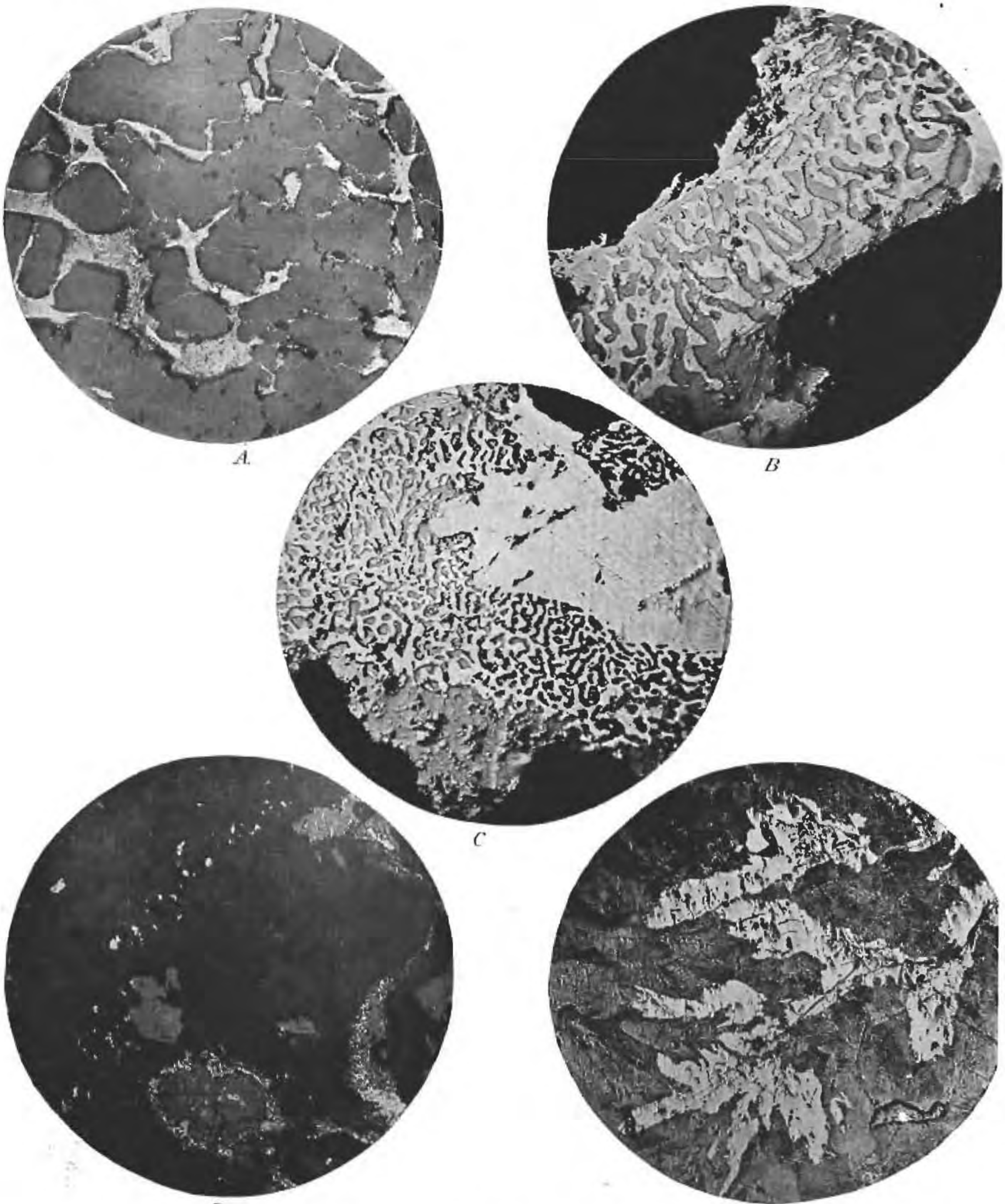
A and *B*. Finely granular or replacement smithsonite ore. *A*, Ore from the May Day mine; shows numerous small cavities attributed to shrinkage, accompanying replacement. The cavities are partly filled with fine drusy smithsonite and a few by calamine. *B*, Monheimite from the Yankee mine; illustrates partial replacement along closely spaced bedding planes and cross fractures, and subsequent removal of unreplaced limestone. Natural size.

C. Finely banded smithsonite-calamine ore. May Day mine. The lighter broad bands originally represented smithsonite and the darker narrow bands calamine; but in this specimen much of the smithsonite has been replaced by calamine. The dark patches represent leached portions stained with films of iron and manganese oxides. Natural size.

D and *E*. Fibrous smithsonite (S) with hydrozincite (H) and fibrous calcite (C), May Day mine. The calcite rests upon a finely botryoidal surface of smithsonite. The hydrozincite in this specimen is finely fibrous and forms a distinct layer between layers of smithsonite. Natural size.



VARIETIES OF OXIDIZED ZINC ORES.



PHOTOMICROGRAPHS OF ORES.

PLATE XXIX.

A. Veinlets of argentite (white) altering to hornsilver (gray) in gangue of granular quartz, Victoria mine; black rim between argentite and gangue is bismuthite. Magnified 100 diameters.

B. Pearceite (gray) and galena (light gray) in "eutectic" intergrowth, forming veinlet in jasperoid, Gem channel, nineteenth level, Gemini mine. Magnified 650 diameters.

C. "Eutectic" intergrowth of galena and pearceite, nineteenth level, Gem channel, Gemini mine. Magnified 246 diameters.

D. Argentite in galena, latter etched black, Eagle and Bluebell mine; argentite shows a strain of white specks across center of area. Magnified 100 diameters.

E. Geocronite (light gray) developing by replacement in galena, Colorado mine. Magnified 30 diameters.

OXIDATION OF ZINC ORES.[1]

GENERAL FEATURES.

The casual observer might believe that zinc blende is absent from the Tintic ores. In fact it is rarely seen in large aggregates. Some of the deep ore of the Gem channel in the Gemini mine and in the Bullion Beck mine contains exceptionally large amounts of this mineral and it is occasionally observed elsewhere. Shipments from the Gemini mine from level 14 contained, according to Mr. J. H. McChrystal, from 2 to 10 per cent of zinc. Ore recently shipped from level 13 north in the Bullion Beck mine contained 15 per cent of zinc, 15 per cent of lead, and 8 ounces of silver to the ton. The microscope shows that almost all the galena contains a small amount of zinc blende disseminated in irregular grains and apparently of the same age as the galena.

It is a striking fact that no oxidized zinc ores are found close to the zinc blende, the relations being just the reverse of those between galena and oxidized lead ores. The oxidized zinc ores are also separated from the oxidized lead ores, except in parts of the Scranton mine, in the North Tintic district. The experiments by Gottschalk and Buehler[2] have shown that in a mixed sulphide body electrolytic action accelerates the oxidation of zinc blende, whereas pyrite or galena, with which it is in contact, is protected from oxidation. Recent experiments by E. T. Allen[3] and others at the Carnegie Geophysical Laboratory have shown that although galena alone begins to oxidize before zinc blende, it soon becomes protected by a coating of difficultly soluble sulphate or carbonate. The sulphate of zinc, on the other hand, is very soluble and is quickly removed when the surface of zinc blende is continuously exposed to attack until the mineral is completely oxidized. During this process the zinc blende may be replaced by covellite, as shown in a specimen from the Black Jack dump.

Only in recent years have bodies of oxidized zinc ores been discovered. They are usually found in the limestone or dolomite footwall of the deposits of galena, and it is evident that the easily soluble sulphate has migrated along the easiest paths of the descending waters, as shown in figure 23 (p. 172), until they reached the carbonate country rock, which then was replaced by smithsonite and calamine, with small amounts of hydrozincite. Deposits of this kind have lately been worked in the Scranton, New Bullion, May Day, Yankee, Gemini, Lower Mammoth, East Tintic Development, Godiva, Uncle Sam (Humbug), Chief, and Colorado mines. Probably they will be found near any of the larger shoots of galena. Thus far no important bodies of this kind have been found along the Iron Blossom ore zone.

The ore is for the most part practically free from lead, but much of that mined in the North Tintic district is a mixed zinc lead or "combination" ore. The relatively pure zinc ore consists principally of ferruginous smithsonite or monheimite (zinc-iron carbonate), with considerable calamine and small amounts of hydrozincite and aurichalcite, accompanied by a gangue of unreplaced limestone and chert, hydrous oxides of iron and manganese, calcite and locally aragonite and gypsum. The smithsonite is gray where unaffected by recent oxidation and brown or black where stained by iron or manganese oxides. It is mostly very fine grained to microgranular and in places contains many small cavities, which appear for the most part to represent decrease of volume due to replacement, but much ore with no cavities has also been found.

Of less common occurrence is ore of the cellular type in which replacement appears to have occurred along certain laminae and the unreplaced limestone to have been later removed. In one specimen of banded ore the banding was seen in thin section to pass directly across the boundaries of former calcite grains and to show no relation to the structure of the limestone, as if the material had been deposited in successive diffusion bands, like the jasperoid of the first stage. (See p. 156.)

Certain openings in the ore, along original bedding planes or fractures, are crusted with yellow to green fibrous smithsonite, with a few alternating layers of chalky-white hydrozincite (Pl. XXVIII). Soft druses of greenish-blue aurichalcite have also been noted but are not common. A little malachite was noted in one specimen, where it formed a thin green druse

[1] A more detailed account of the oxidized zinc ores of the Tintic district, by G. F. Loughlin, has been published in Econ. Geology, vol. 9, pp. 1-19, 1914.

[2] Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 5, pp. 28-36, 1910; vol. 7, pp. 15-34, 1912.

[3] Washington Acad. Sci. Jour., vol. 6, p. 22, 1916.

over a film of hydrozincite, which in turn coated fibrous smithsonite. The calamine occurs for the most part as druses in openings in smithsonite and adjacent gangue materials. It is also present in small amount disseminated in smithsonite or limestone.

Hydrous oxides of iron, principally limonite, occur as coloring matter in the brown ore and as fracture fillings along which the zinc ore has been leached, but most abundantly as layers from a few inches to a few feet thick between bodies of oxidized lead and zinc ore. Much if not most of the iron oxide has evidently been derived by oxidation of the ferruginous smithsonite. The crusts of soft brown material, however, that line some of the openings appear to have been deposited directly from solution. Hydrous manganese oxide is present as a black amorphous material which has the same mode of occurrence as the iron oxides. It is very subordinate to the iron oxides and is more prominent in the lower parts of stopes than elsewhere. In some places the black manganese mineral resembles hetaerolite, the hydrous zinc-manganese oxide, but none of it sufficiently pure to permit chemical determination could be found. The other gangue minerals have the same characteristics as in other oxidized deposits of the district.

PARAGENESIS.

Comparative study of a large number of specimens shows the following paragenesis of oxidized zinc ores and related minerals, which is shown diagrammatically in figure 22. The granular ferruginous smithsonite was the first ore mineral to form, replacing limestone. This was apparently followed by the oxides of iron and manganese, which were in large part derived by oxidation of the smithsonite and were still forming during the growth of the other minerals. The fibrous smithsonite and hydrozincite followed, the latter in part as a probable alteration product of granular smithsonite and in part alternating with fibrous smithsonite. Calamine is distinctly later than fibrous smithsonite, but its relations to hydrozincite, aurichalcite, and malachite are not clear. Calcite was distinctly later than all the zinc minerals. No aragonite or gypsum were found in contact with zinc minerals. The low zinc content of one aragonite specimen, however, suggests a close time relation with hydrozincite, and the solubility of gypsum in water, greater than that of calcite, suggests that it was the latest of all the minerals.

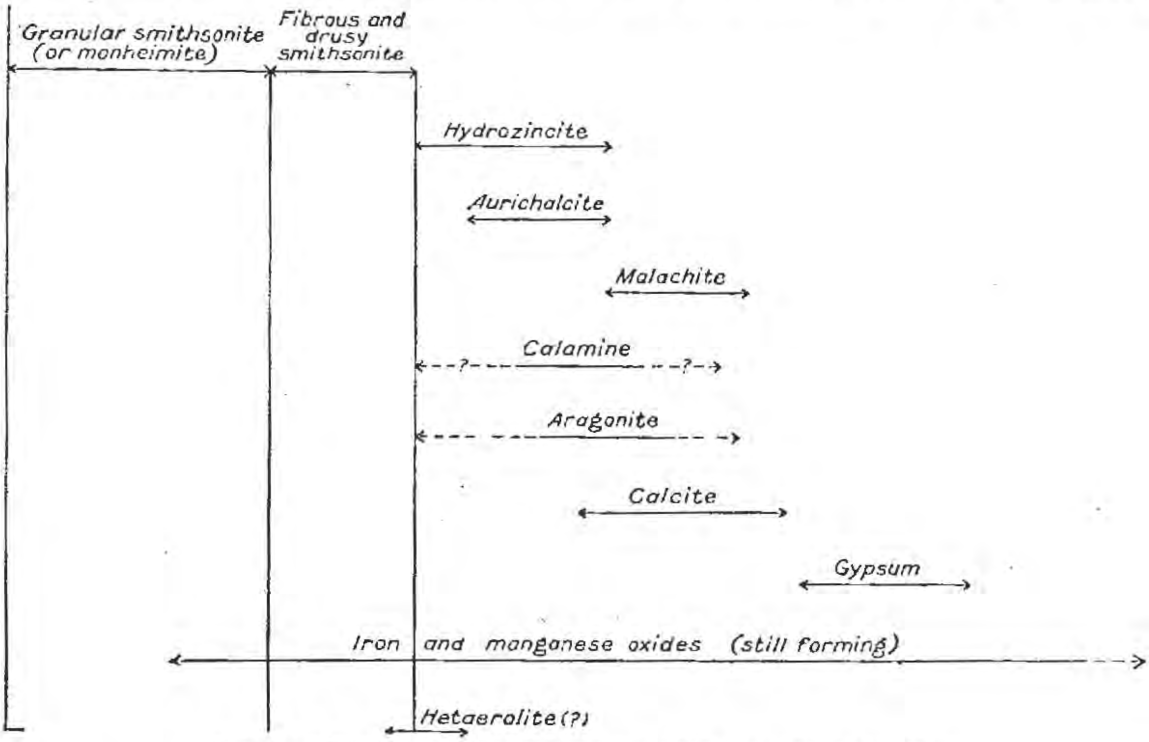


FIGURE 22.—Diagram illustrating paragenesis of oxidized zinc and related minerals.

GENESIS.

There is no question that the oxidized zinc ore bodies were derived from original bodies of

mixed lead and zinc sulphides.[1] The zinc blende was oxidized to the very soluble zinc sulphate, which was carried downward, whereas the relatively insoluble oxidation products of galena remained in the original ore body. The zinc sulphate solution, moving along fractures and bedding planes, replaced the purer and more permeable beds of limestone with which it came into contact, forming the granular smithsonite. The drusy and fibrous smithsonite, the hydrozincite, and other carbonates were formed either by a recrystallization of smithsonite along cavity walls or by precipitation during a later stage of oxidation, after the sulphur necessary to form zinc sulphate had been largely exhausted and carbon dioxide became an active acid radicle. The silica in the ground water, derived from siliceous portions of primary ore or from porphyry that formerly overlay the present surface, also became an active acid radicle during the late stages of oxidation, reacting with smithsonite along watercourses and depositing calamine.

The zinc-lead or "combination" ore in the North Tintic district was formed by the same chemical processes as the zinc ores free from lead, but the original lead-zinc sulphide ore was evidently due to impregnation rather than complete replacement of the limestone. When the zinc blende was oxidized, limestone was at hand to react immediately with the resulting zinc sulphate before it could migrate from the lead ore. The only remnants of sulphides seen in the North Tintic district are disseminated in limestone and do not form solid masses.

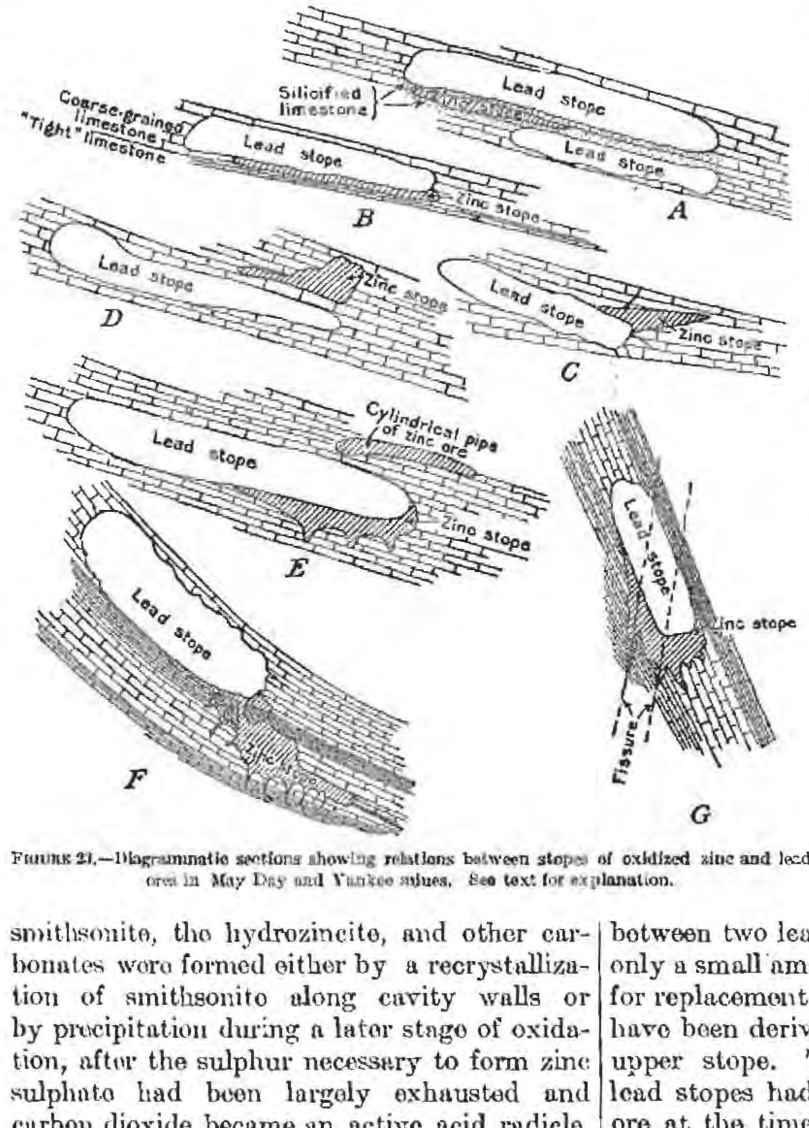


FIGURE 23.—Diagrammatic sections showing relations between stopes of oxidized zinc and lead ores in May Day and Yankee mines. See text for explanation.

VARIATIONS IN SIZE AND DISTRIBUTION OF OXIDIZED ZINC ORE BODIES.

Variations in the size of the oxidized zinc ore bodies and their relations to the lead stopes are due to a number of causes, such as variations in the quantity of original zinc blende available in different bodies, in the rate of downward migration, in the arrangement of openings along which the solutions flowed, and in the permeability of the limestone beds with which they came in contact. These variations are illustrated diagrammatically by figure 23. Figure 23, *A*, represents a place in the Yankee mine where the rock between two lead stopes is mostly silicified and only a small amount of limestone was available for replacement by zinc carbonate, which must have been derived from the upper part of the upper stope. The down-dip ends of these lead stopes had not been prospected for zinc ore at the time of the writer's visit. Figure 23, *B*, represents another place in the same mine where the zinc carbonate replaced a thin stratum of coarse-grained limestone that formed the immediate floor of a lead stope but could not penetrate a dense or "tight" bed below it. In the stopes illustrated by figure 23, *C* and *D*, also in the Yankee mine, the floor of the lead stope was impervious and the

[1] For a more complete discussion of the genesis, see Loughlin, G. F., The oxidized zinc ores of the Tintic district, Utah: Econ. Geology, vol. 9, pp. 11-16, 1914.

zinc-sulphate solutions had to escape through the down-dip portion of the roof. It is significant that the tops of these zinc stopes in the hanging wall are lower than the tops of the corresponding lead stopes. The same conditions are shown by the upper zinc ore body represented in figure 23, *E* (Yankee mine), where part of the solutions migrated along a watercourse in the lower hanging wall; but here a greater part permeated and replaced the lower footwall. Figure 23, *F*, represents more complicated conditions that controlled the formation of one of the larger zinc ore bodies in the May Day mine. Here the floor of the lead stope is a "tight" limestone that the zinc ore could replace only along certain open bedding planes and fissures. The solutions for the most part migrated downward along these fissures to a coarse-grained permeable bed which was readily replaced, the solutions moving along fissures and bedding planes until their supply of zinc was exhausted. Figure 23, *G*, represents general conditions in the Gemini and Ridge and Valley mines, where the lead stopes are nearly vertical and the course of the zinc solutions was nearly vertically downward along bedding planes and fissures. The relation of oxidized zinc to lead ore in the Lower Mammoth mine is shown in figure 34 (p. 221).

RANGE IN METAL CONTENTS.

The zinc content of small samples may range from that of pure smithsonite or calamine, over 50 per cent, down to 15 per cent or less in limestone that is only slightly impregnated with zinc minerals. Shipping ore has mostly contained from 29 to 35 per cent zinc, but for a time early in 1913 ore containing as low as 20 per cent was shipped. Selected samples of the ore, free from insoluble gangue matter, according to Zalinski [1] contain no silver or gold, but the average ore shipped from the May Day mine in 1912, according to Heikes,[2] contained 0.027 ounce of gold and 2.20 ounces of silver to the ton and 2.57 per cent of lead.

OXIDATION OF SILVER ORES.

So far as has been ascertained the galena of the Tintic district owes its tenor of silver to irregularly distributed argentite (p. 160; Pl. XXIX, *D*), which was either deposited contemporaneously with the galena or replaced it immediately after its development. During the oxidation this silver sulphide was undoubtedly converted to sulphate, which, being easily soluble, may have migrated for some distance—rarely, however, beyond the confines of the siliceous deposit. The oxidized zinc ores in the limestone contain very little or no silver. The enargite, tetrahedrite, and famatinite doubtless also contained silver sulphide, but whether it was free or in chemical combination has not yet been fully ascertained. During the oxidation the silver sulphate was in part reduced to sulphide, the process being aided probably by the organic matter abundantly contained in limestone and dolomite, and a second generation of argentite was thus formed. A large part of the silver was precipitated as cerargyrite by the ever-present sodium chloride in the mine water, and cerargyrite is, in fact, the most common silver mineral in the Tintic district. Some cerargyrite resulted from the direct replacement of argentite, and native silver was produced by the oxidation of the chloride or the sulphide.

Barite may be rich in silver, doubtless through secondary processes precipitating silver chloride. Some of the massive copper-stained barite in the Centennial Eureka mine contained 80 ounces of silver and $10 in gold to the ton.

The question of what happens to the silver in galena during oxidation is one of considerable interest. S. F. Emmons,[3] in his Leadville report, states that "the greater richness in silver of galena over cerusite in this region is very noteworthy," and that, according to L. D. Ricketts,[4] the average silver tenor of the cerusite of Carbonate Hill is less than 40 ounces to the ton, whereas the galena averages 145 ounces to the ton. The richness of the galena mentioned by Emmons strongly suggests enrichment.

At Tintic the galena is much poorer in silver, containing from 10 to 60 ounces to the ton. Some careful assays were made to ascertain the general application of the relations set forth by Emmons. Some pure galena from the Victoria mine was found by Prof. E. E. Bugbee to contain 0.02 ounce of gold and 20.8 ounces of silver to the ton. Coarse galena from level 14

[1] Zalinski, E. R., Gold and silver in oxidized zinc ores: Eng. and Min. Jour., vol. 97, pp. 1305–1306, 1914.

[2] Heikes, V. C., U. S. Geol. Survey Mineral Resources, 1912, pt. 1, p. 902, 1913.

[3] Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey, Mon. 12, p. 553, 1886.

[4] Ores of Leadville, p. 87, Princeton, 1883.

ïemini assayed a trace of gold and 18.8 of silver. A heavy lead carbonate ore e Colorado mine yielded 0.04 ounce of d only 7.52 ounces of silver. A cuprite lachite ore from level 13 of the Centenreka contained a trace of gold and 8.75 of silver. The low tenor of the oxidized ores is attested by a shipment of such n the Eureka Hill mine. According to W. Riter, it contained 27.16 per cent of 0.012 ounce of gold, and only 1.67 of silver.

ecimen from the Colorado mine, taken 300-foot level near the Sioux line, l galena, anglesite, and cerusite. The which was a banded mixture of "steel" arse galena partly converted to anglesite the cleavage lines, was found to contain nce of gold and 3.25 ounces of silver to n. The anglesite crust immediately ad- contained 0.7 ounce of gold and 19.2 of silver; the lead carbonate imme- adjoining the anglesite gave 0.8 ounce d and 18.06 ounces of silver. In this ıen, therefore, the cerusite and anglesite n about the same amounts of silver and but the galena was very much poorer, seems as if the oxidation had resulted distinct enrichment both of silver and The ores of the Colorado mine con- largely of heavy carbonate with some ııl galena, and their average silver con- was about 45 ounces to the ton.

order to obtain an idea of the relative ess of coarse and "steel" galena, a speci- from the Eagle and Blue Bell, which ed both varieties in juxtaposition, was ed. The coarse galena, which was mixed about 30 per cent of barite, yielded 0.01 e of gold and 50 ounces of silver to the the adjoining "steel" galena gave 0.03 of gold and 46 ounces of silver, showing in this material there is no strongly ced difference.

appears that probably no general rule be established, but the relative richness nds on how quickly and effectively the r sulphate is transformed to chloride and hide. With regard to the specimens from Colorado mine at Tintic, it seems certain no impoverishment by extensive migra- of the silver from the ore body can have taken place, but rather that a certain amount of enrichment has been effected, probably in the main through reduction of volume during oxidation.

The presence of secondary argentite has been abundantly proved. The analyses of wholly oxidized lead ores (p. 162) show that in several places a considerable amount of silver sulphide was dissolved by nitric acid, in which silver chloride is insoluble.

A specimen of rich ore from the 1,050-foot level of the Victoria mine, investigated by Messrs. Means, Whitehead, and Wells, proved especially instructive. It is a fine-grained mottled dark-gray, heavy compact rock, no doubt representing a local enrichment. An assay of the heaviest part yielded 0.77 ounce of gold and 6,980 ounces of silver to the ton, or about 22 per cent. A thin section shows a fine-grained gangue of quartz and barite traversed by a network of argentite (Pl. XXIX, *A*). The argentite is in places replaced by cerargyrite, and the argentite veins are lined by an opaque milky aggregate, which proves to be bismuthite (bismuth carbonate). Cerargyrite and a yellow substance, perhaps bismite, in part, coat joint planes. The argentite is unquestionably secondary, for the delicate network of it cuts across all the older textures. Small grains of native yellow gold occur in the argentite. An analysis of this specimen runs as follows:

Analysis of rich silver ore from Victoria mine.

[R. C. Wells, analyst.]

Loss on ignition	3.57
Insoluble in HNO_3	66.10
Soluble in HNO_3:	
CO_2	2.48
Cl	None.
As_2O_5	.05
P_2O_5	None.
Cu	None.
Ag	4.15
PbO	.31
Fe_2O_3	.92
CaO	.76
MgO	None.
Bi_2O_3	18.07
SO_3	.58
	96.99

Upon treatment with ammonia 1.08 per cent of silver chloride was dissolved, which is included in the material "insoluble in HNO_3" as stated above.

An additional determination gave the following results:

Ag soluble in hot HNO_3		4.45
Ag soluble in one-fourth cold HNO_3		None.
Total S		2.62
Total BaO		8.72
S required for $BaSO_4$	1.82	2.48
S required for 4.45 per cent Ag as Ag_2S	.66	
S available for other constituents		.14
Bi_2O_3 soluble in one-fourth cold HNO_3		20.46
$Bi_2O_3CO_2$ calculated		22.40
CO_2 available for other constituents		.54

This remarkable ore is thus proved by chemical and microscopic study to be a compound of quartz, barite, argentite, and bismuthite, with some cerargyrite resulting from the decomposition of the secondary argentite. It represents undoubtedly a great enrichment of silver and gold from considerable masses of ore, and both these metals, as well as the bismuth, must have migrated a considerable distance. There are no remains of primary sulphides in the ore.

Another interesting specimen of oxidized ore in which the secondary nature of the argentite is clearly shown came from the rich winze on the 1,200-foot level at the north end of the Eagle and Blue Bell mine. The rock, originally a jasperoid, is now in part replaced by argentite and horn silver and coated by soft yellow crusts containing iron, lead, and bismuth. Argentite occurs throughout the specimen in spots large enough to be identified with the naked eye. Brown horn silver coats joints and druses and is in part crystallized. In polished sections the argentite is seen to be disseminated in small grains which have a marked concentric structure and which are in part converted to horn silver. Small specks of bright yellow gold occur both in argentite and quartz.

The chloride of silver (cerargyrite, or horn silver) usually occurs at Tintic as brown crusts and films on joint planes of jasperoid or oxidized ore. It is abundant, though generally not conspicuous, in all the silver-lead mines and in mines that contain highly siliceous ores, like the Iron Blossom. Native silver is much less abundant but in many places accompanies the chloride. The most extensive bodies of pure silver ores occurred in the upper levels or at medium depths of the Eureka Hill, Bullion Beck, and Gemini mines, but rich horn-silver ores also occurred in abundance, for instance, in the 1,200-foot level of the Eagle and Blue Bell and in many other deep mines. A small but rich body of oxidized silver ore was found in kaolin on level 21 of the Mammoth mine.

The richest of the oxidized silver ores are not found in the oxidized lead ores but in highly siliceous ores poor in lead. Much ore of this kind was mined in the Gemini and the Eureka Hill. This distribution of the rich ore may be caused by extensive migration of the silver solution into siliceous masses underlying the lead shoots, for it is unquestionably true that the silver migrates farther than the lead; or it may be due to a higher primary silver content of certain kinds of siliceous ore containing primary disseminated tetrahedrite. These questions are difficult to decide, for most of these ore bodies were mined out long ago.

Gemini ores of this kind contained, for instance, 6 to 7 per cent of lead and about 75 ounces of silver to the ton, and similar Eureka Hill ores from the Billings stope yielded 5 per cent of lead and 20 to 30 ounces of silver.

SECONDARY SILVER SULPHIDES.

Complex silver sulphides are not common in the Tintic district. The rare pearceite, from the exceptional Gem shoot of the Eureka Hill and Gemini mines, is described on page 179. The tetrahedrite and enargite contain silver but apparently not in great amount. Proustite, or arsenical ruby silver, has been reported from a few places. The only occurrence that could be examined was a specimen from the Chief mine, kindly given by Mr. Walter Fitch. Ruby silver is also reported from the Gem shoot in the Gemini mine, level 19.

The specimen from the Chief mine was examined by Messrs. Whitehead and Means and shows a predominating fine-grained jasperoid with drusy cavities coated by small quartz crystals. Yellow coatings on the surface of the specimen prove to be bismuthite. Numerous small grains of proustite show in the specimen, and a thin coating of the same mineral covers a joint plane. In thin section the fine-grained jasperoid is dotted with oxidized products, such as limonite and malachite, and contains barite laths partly replaced by quartz. These occur both in the earlier and in the later quartz, which coats and fills cavities. Grains

of cerusite replace the quartz, and malachite fills some of the vugs. The ruby silver is contained in the coarse quartz, and most of it is a late product filling the centers of the drusy cavities. Polished sections show that the proustite is in part replaced along its margins by a mineral identified as argentite (Pl. XXVII, *E*, p. 165). A third metallic mineral is probably present but has not been identified.

The somewhat scant evidence indicates that complex and rich silver sulphides are absent from the normal primary ore and that ruby silver was deposited either soon after the end of the principal epoch of mineralization or more probably during the oxidation.

OXIDATION OF BISMUTH ORES.

Bismuth has not been found in the Gemini ore zone, but it occurs in considerable abundance in the Mammoth zone and in the southern part of the Godiva zone. The Boss Tweed mine yielded a large amount of bismuthite, according to Tower and Smith, and lately bismuth arsenate (arsenobismite) has been encountered in commercial quantities in the Mammoth mine. The siliceous ore of the Victoria contains bismutite associated with argentite (p. 174), and dark-yellow mammillary crusts on corroded quartz from the Eagle and Bluebell were found to consist of plumbojarosite mixed with bismite (Bi_2O_3). (See p. 162.)

The primary bismuth sulphide from which these oxy-salts have been derived has not so far been discovered. The occurrence in the Mammoth mine perhaps points to a complex sulpharsenide of bismuth and copper. It does not seem likely that bismuthinite (Bi_2S_3) could have escaped notice if it formed part of the primary association.

CONCENTRATION OF GOLD DURING OXIDATION.

OCCURRENCE.

Most of the Tintic copper ores and some of the large bodies of siliceous low-grade lead ore like those of the Iron Blossom mine contain from \$4 to \$12 in gold to the ton. It is not likely that the tenor of these ores has been notably increased by migration of the gold, though it may have been increased somewhat by reduction of volume during the oxidation. The distribution of gold in some of these ores is very irregular, though a certain average may be maintained. A series of assays from a stope in the Colorado mine, for instance, showed from nothing up to \$6 to the ton in gold. Another stope in Iron Blossom No. 3 gave assays ranging from \$0.80 to \$18.20, the average of all the assays being about \$5. Certain spots and parts of the shoots are much richer than the rest, and these undoubtedly indicate local migration and concentration. Some examples of these conditions, taken at random from a long series of assays, are set forth below:

Gold, silver, and lead content of certain parts of ore shoots.

Colorado mine, Spanish Fork stopes; siliceous lead ore.

Gold. (value per ton).	Silver (ounces per ton).	Lead (per cent).
\$0.80	17	16.5
2.40	44	21.0
8.00	72	13.5
36.40	361	8.0
60.00	1,102	21.8
104.00	1,108	49.7

Iron Blossom No. 1, South stope No. 3; siliceous ores poor in lead.

Gold. (value per ton).	Silver (ounces per ton).	Lead (per cent).
\$1.20	11	....
6.00	22	....
28.00	180	....
120.00	66	....
284.00	152	....
508.00	26	....

Iron Blossom No. 3, Van stope.

Gold. (value per ton).	Silver (ounces per ton).	Lead (per cent).
\$1.20	4	3.00
2.80	37	....
6.00	33	7.90
8.40	43	....
19.60	222	3.00

In the ores of the Colorado mine high gold content is accompanied by rising and very high tenor in silver, but the lead rather decreases or at any rate bears no direct relation to the gold. These ores may contain some residuary galena and undoubtedly contain argentite and horn silver.

In the Centennial Eureka all the copper ore carries from \$4 to \$15 to the ton in gold, but on many levels—for instance, on levels 2, 3, 9, 14, and 16—much richer local siliceous masses are found, so that these rich gold ores may be found at any depth. Some of this ore contains several ounces of gold to the ton, and one carload of 50 tons from level 9 is said to have averaged 16 ounces, or almost \$320, to the ton.

Rich spots are often found in the Eagle and Blue Bell and Victoria mines in honeycombed quartz ore, with a little oxidized bismuth and lead minerals. Some of the siliceous ores averaged $10 in gold and 20 ounces of silver to the ton, with 1 to 3 per cent of lead, but the richest ore on the 1,200-foot level yielded $80 in gold, 130 ounces of silver, and 2 per cent of lead. Heavy galena ores are never rich in gold, enargite ores generally contain a few dollars' worth to the ton, and oxidized copper ores appear to be poor in gold.

On the 1,100-foot level in the Victoria was found an almost spherical mass of ore 30 by 24 feet. This is said to have averaged $40 in gold and 2 or 3 ounces of silver to the ton, but it contained no lead or copper.

The Mammoth mine has been rich in gold, mostly associated with the copper ores. Parts of the Apex stope were rich in gold from the surface down to level 15. The Silveropolis copper-lead shoot was likewise rich in gold, but the Welding copper shoot contains only $1 to $2 in gold to the ton. The poor siliceous ores of the lower levels are valuable principally for their gold content, as they contain little silver and no lead or copper.

The North Star mine, on the Godiva ore zone, is said to have yielded more gold in proportion to the other metals (lead and copper) than any of the other mines of the district. Two-thirds of the value of the ore was in gold. The ore from this mine was not available for examination.

CHARACTER OF ORES.

Native gold is not visible in the distinctly primary ores, but many of the secondary gold ores show small grains and flakes of it; these are usually of bright yellow color, indicating that only a small amount of silver is alloyed. Some gold in the Mammoth mine, level 10, and in the North Star mine is said to have occurred in barite, but it is a question whether this is not an accidental association, barite being common in all the copper mines. Of more significance is the occurrence of earthy manganese dioxide in most of the mines that contain shoots of secondary gold. This was particularly observed in the Mammoth mine, where the association is well known to the miners. It is said that in the Silveropolis shoot of this mine, down to level 6, much manganese accompanied native gold. Considerable manganese was also observed in the Victoria, Centennial Eureka, and Iron Blossom No. 1 mines. During the present examination no gold was seen directly embedded in manganese minerals in any of these mines, but there can be little doubt that with free sulphuric acid available from the oxidation of sulphides and sodium chloride supplied to the mine waters by winds from the deserts of the Salt Lake region the necessary conditions for the generation of chlorine and the solution of gold are present, and that migration on a moderate scale may be effected at any level above that of ground water.

There are three modes of association of secondary native gold:

1. Gold occurs in small grains and flakes in secondary argentite, as is shown convincingly by specimens from the Victoria and Eagle and Blue Bell mines (p. 175). The gold is rarely visible with the naked eye or in thin section but is easily perceived in polished sections. A large part of the secondary gold belongs to this class.

2. Gold occurs in highly siliceous ores as bright-yellow flakes on joint planes. This mode of occurrence is well shown in much of the rich gold ore from the Victoria mine and is probably also well exemplified in the Mammoth and Centennial mines. Such ores are poor in silver. Small specimens of the rich gold ore from the Mammoth, containing abundant visible gold and probably taken from the gold shoot on level 15, show an allotriomorphic jasperoid of medium grain. The gold occurs with a little limonite along the planes separating the small quartz grains.

3. Gold is sometimes found in limonite. One such occurrence was noted in the May Day mine, where a lead shoot was underlain by a seam of dark-brown earthy limonite that was said to be shipping ore containing about $20 in gold to the ton. Specimens collected here proved, however, to be poor, and no metallic particles were found.

ORE FROM THE GEM CHANNEL OF THE GEMINI MINE.

OCCURRENCE.

In the so-called Gem channel, the most westerly chain of deposits of the Gemini mine, there appears an ore of such peculiar character that it must be described separately. It differs

markedly from the ores found elsewhere in the mine or in the entire district, and derives additional interest from the fact that most of it was found below the water level, where for a few years explorations were carried on by means of a winze from the 1,650-foot level, at which the water now stands in the mine. (See p. 189.) The shoot, which is very irregular, extends along the fissure line known as the Gem channel. It was first found a little above the 1,300-foot level and was followed down to the 1,900-foot level. Although at present the water stands at 1,650 feet in the Gemini mine the next few levels above this are very wet, at least including the 1,400-foot level.

The Gem channel carries no ore above this shoot in the Gemini mine, but bodies have been mined in the Bullion Beck mine, to the south, and in the Eureka Hill and Centennial mines, still farther in the same direction. The old workings in the Bullion Beck are scarcely accessible, but so far as could be ascertained neither these nor the workings farther south carried similar ore. Much of the ore in these mines along this channel was, however, thoroughly oxidized.

Characteristic sulphide ore was found in abundance on the 1,400-foot level, and similar ores were collected on the 1,650-foot level. A suite of fine specimens from the 1,900-foot level, obtained through the kindness of the Messrs. McChrystal, was carefully examined.

Ore similar to this was not found elsewhere in the district. At three other places, at least, the water level has been approached or reached in ore. One is along the Tank and Intermediate "channels" of the Gemini, on the 1,650-foot level, where apparently no abnormal ore has been found. Another locality is in the Mammoth mine, where the low-grade ore is entirely oxidized. The third place is in the Chief mine on the 1,800-foot level where lead ore was recently found a few feet above the water level. Specimens of this ore were obtained through the kindness of Mr. Walter Fitch and proved to be a high-grade galena ore with much anglesite and cerusite, a little zinc blende, and a few small crystals of galena. The ore specimens yielded 0.04 ounce of gold and 65 ounces of silver to the ton. In similar ore from the Eagle and Blue Bell mine the galena upon etching in polished sections was found to contain irregularly distributed grains of argentite (Pl. XXIX, *D*), possibly also some secondary argentite along the margins of the galena, but differed in no essential way from the normal high-grade lead ore of the district. This fact makes it difficult to attribute the peculiar and rich ore of the Gem channel to sulphide enrichment by descending waters. It is possible that during the Pleistocene epoch of Lake Bonneville the water level in the district stood a few hundred feet higher than now, but if so the ore at or close to the present water level in other mines should also show evidence of sulphide enrichment, which it does not, so far as observed.

The interesting fact that this ore is partly oxidized below the water level is mentioned above (p. 161). The vugs contain cerusite crystals joined with silver threads; nests of wire silver are common, and complete oxidation, with the development of cerusite, limonite, and malachite is shown even on the 1,900-foot level. This evidence indicates that the water level, either before the Lake Bonneville epoch or during an arid stage of the epoch, was even lower than it is to-day.

TENOR IN SILVER.

Ores very rich in silver have been mined on many levels in the Gemini mine, but these owed their tenor to horn silver and were in general almost wholly oxidized. Ordinary sulphide ores of the lower levels in other "channels" of the mine are not excessively rich, the galena rarely containing more than 50 ounces of silver to the ton. The sulphide ores of the Gem shoot, on the other hand, are exceptionally rich in silver and contain from 50 to 3,000 ounces of silver to the ton, even when mixed with considerable gangue. A series of assays by Prof. E. E. Bugbee yielded the following results:

Assays of silver ores of Gem shoot.

[Ounces per ton.]

	Gold.	Silver.
Pure galena, 1,400-foot level (No. 320)	Trace.	18.80
Pure enargite, 1,900-foot level (No. 263)	0.08	45.50
Galena, pearceite, marcasite, and zinc blende, with much gangue, 1,400-foot level (No. 321)	.01	64.90
Coarse galena with pearceite, 1,900-foot level (No. 2)	.02	628.00
Coarse galena and zinc blende, 1,900-foot level (No. 3)	Trace.	19.94
Medium-grained galena with pearceite, 1,900-foot level (No. 4)	Trace.	1,529.00
Galena, native silver, and pearceite, 1,900-foot level (No. 5)	Trace.	2,528.00

A.

B.

ORES FROM THE GEM CHANNEL, GEMINI MINE.

A. Ore from 1950-foot level, showing veins of galena and pearceite in jasperoid. Natural size.

B. Ore from 1400-foot level, 300 feet north of winze, showing breccia of jasperoid and dolomite, galena, pearceite, and zinc blende surrounded by replacement rings of marcasite (?). Natural size.

These assays seem to indicate that the pure galena and zinc blende contain comparatively little silver, like the enargite, which occurs very sparingly. The galena in specimen 320 in polished section was found to contain only a few scattered grains of argentite. Specimen 321 is the one figured in Plate XXX, *A*, and half of the sawed specimen was used for the assay. Specimens 2, 4, and 5 all contained pearceite mixed with galena and secondary wire silver in places.

The smelter analysis of part of the ore in a raise from the 1,400 to the 1,300 foot level gave: Lead, 11.65 per cent; zinc, 2.6 per cent; iron, 3.55 per cent; sulphur, 4.65 per cent; silver, 114.9 ounces; this is very similar to all the ore shipped from this shoot. The average of all the ore shipped is said to have been 50 ounces of silver to the ton, which is high for the mine.

CHARACTER OF ORE.

The Gem shoot occurs in a dark fine-grained dolomite that is in places black and shaly. So far as examined the ore has a brecciated structure, and the ore minerals mainly fill the interstices between the fragments of dark fine-grained jasperoid and dolomite. Much of the jasperoid in the fragments is identical with the ordinary low-grade ore of the mine and contains finely disseminated galena, zinc blende, and pyrite. The jasperoid in places shows veinlets of chalcedony cut off at the edge of the fragments.

The coarser-grained sulphide minerals characteristic of this ore in part replace the cement of the breccia, in part they are pure filling, and in part they replace the dolomite fragments, a mode of occurrence not known elsewhere in the mine or in the district, except in some of the outlying mines in North and East Tintic.

The ore minerals consist of coarse galena, much zinc blende, a little enargite, marcasite (?), and pearceite. Their deposition was accompanied by the formation of a little quartz in small, clear crystals, seemingly the last mineral to form. The photograph of a typical specimen, polished for the purpose, is reproduced in Plate XXX, *B*.

The galena occurs in cubes and large grains with a tendency to rounded growths. Some of it forms narrow and branching veinlets in jasperoid (Pl. XXX, *A*) and may be surrounded by a rim of yellow zinc blende. It is very commonly intergrown with pearceite and zinc blende in the manner described below.

Zinc blende occurs in small rounded concretionary masses with delicate concentric structure; these spherulites contain droplike inclusions of galena.

Marcasite is found coating crevices and fragments in the shoot as low as the 1,900-foot level. It is plainly crystallized, though the crystals are minute. In the ore as represented on Plate XXX, *B*, iron disulphide forms small solid spheres, some of which showing free in vugs, or it forms hollow spheres surrounding the other minerals and showing as rings in the polished sections. This mineral, which is probably marcasite, has an extremely fine radial-concentric texture.

A series of assays indicate that pure galena, zinc blende, and enargite contain comparatively little silver. The principal silver-bearing mineral is with considerable confidence identified as pearceite, and occurs in all of the rich specimens. It occurs massive with galena, has a dark-gray color, blackish streak, and hardness about 3, fuses very easily in alcohol flame, and contains much silver, arsenic, and sulphur and a considerable amount of copper. Under the metallographic microscope it looks greenish gray, much like tennantite. Native silver forms abundantly wherever decomposition has set in.

Pearceite is characteristically intergrown with galena, the boundaries being sharp and regular. In some places it is surrounded by galena; in others it is intergrown with galena, the texture resembling that of a typical eutectic.[1] (See Pl. XXIX, *B*, *C*, p. 169.) The "eutectic" texture is probably caused by the replacement of galena by pearceite.

Covellite, a secondary mineral, replaces both galena and pearceite in blades or intimately branching form, some of it recalling "eutectic" texture. This mineral is fairly common but is rarely visible except under the microscope.

Galena is intergrown with zinc blende, but zinc blende, marcasite, and pearceite are nowhere intergrown. Pearceite appears to be the latest mineral.

This ore differs markedly from the normal ores of the district in the abundance of a rich silver sulpharsenide, in the concretionary or

[1] For a more detailed description of this interesting occurrence, see Whitehead, W. L., The paragenesis of certain sulphide intergrowths: Econ. Geology, vol. 11, pp. 1-13, 1916.

spherulitic texture of some of the zinc blende and marcasite, and in the replacement of dolomite by the sulphide. So far as observed any concentration of argentite or ruby silver in the ores of the district is caused by comparatively late enrichment, which probably took place during the oxidation. It can be said with confidence that these rich silver ores of the Gemini mine are later than the first phase of the mineralization (p. 154), and they differ very strongly from the ores of the second phase. It is therefore held that the ores of the Gem channel were deposited after the principal phases of the mineralization were completed but before active oxidation had begun. It can not be asserted that they were formed by descending solutions, but they were probably formed by cooler solutions, ascending or descending, in which the silver content had been abnormally increased because they reached their place of deposition by traversing ores of medium richness already deposited.

RELATION OF THE ORES TO THE IGNEOUS ROCKS.

GENERAL FEATURES.

The veins of Tintic intersect monzonite and monzonite porphyry and may be productive in these formations. They nowhere, so far as known, intersect rhyolite, although they are more recent than the rhyolite effusion. The relation of the deposits to the rhyolite therefore becomes a matter of considerable interest, which is more fully discussed in a following paragraph.

The sedimentary area contains dikes of rhyolite, latite-andesite, rhyolite porphyry (Swansea rhyolite), and monzonite porphyry. In many mines dikes are not seen, but they are found in the underground workings of the Gemini, Centennial, Apex, May Day, Yankee, Carisa, Beck Tunnel, and Iron Blossom. None of these dikes are replaced by ore, though ore may occur close to them, even up to the immediate contact. Most of the dikes are more or less clayey and contain sericite, calcite, and pyrite as replacement deposits; the pyrite occurs usually in very minute grains. In places, as in the Centennial mine, the igneous rock may yield a trace of silver.

In the region of the Iron Blossom, where there are many dikes, evidence of a slight mineralization may be found along the contacts of these dikes even if they occur in nonproductive parts of the mine; this is expressed by limonite stain and silicification and here and there by a low content of silver.

The dikes are undoubtedly older than the ore deposits and the relation expressed above is therefore interpreted as indicating the great selective power of precipitation by the limestone or dolomite. The conditions in the Centennial mine are particularly instructive, for here there are several dikes and flat masses of Swansea rhyolite porphyry in the midst of great ore bodies, and none of this igneous rock has been replaced by ore.

CONTACT OF RHYOLITE AND LIMESTONE.

The vicinity of the May Day mine offers excellent opportunities for an examination of the contact between the rhyolite flow and the limestone. At the surface the contact lies close to the shaft and the portal of the upper tunnel. It is first exposed near the Uncle Sam shaft on the lower tunnel level. The tunnel, which trends south-southwest, reaches the Uncle Sam shaft in a distance of 450 feet and is in rhyolite at first compact but gradually growing more clayey. The contact of rhyolite and limestone lies about 150 feet south of the shaft and stands almost vertical. It is followed by a vein of kaolin 1 foot wide; adjoining this is 1 to 2 feet of a rusty material with limonite, which looks like oxidized pyritic rock, and this changes gradually into normal limestone; in places the limestone is cellular and silicified. Pyrite in finely divided form is also contained in the clayey rhyolite, and small foils of gypsum are abundant in some places. The contact of the two rocks is certainly mineralized to some extent by pyrite, though no commercial ore is found. These relations show that the contact from the surface to the tunnel level is vertical or rather overhanging.

On the 400-foot level, or 200 feet below the tunnel, the contact is met about 100 feet south of the shaft—that is, almost vertically below the upper contact. The rhyolite is clayey in part, but in places it looks like sandstone or it may be hard, like quartzite; it is probably tuffaceous. The contact is difficult to locate with exactness, for both rocks are silicified near the dividing plane. The limestone is porous and contains barite crystals in the

pores, and a few feet back of the contact cerusite and galena appear on a fissure. Much gold is occasionally found in the silicified material.

On the 700-foot level the contact is shown in a drift east of the shaft; it dips 20° E. and is indistinct and silicified. The material along the contact is said to carry no metals in determinable quantity. The rhyolite is a dark clayey breccia with much pyrite or marcasite, but this sulphide, according to the superintendent, Mr. C. C. Griggs, carries no precious metals.

On the 800-foot level the contact is 450 feet north of the shaft, which indicates a considerable flattening out below the 400-foot level. Here black clayey rhyolite tuff rests on brecciated limestone.

The contact is also visible in the old Godiva workings. The Godiva shaft is 400 feet northwest of the Uncle Sam shaft, and its collar is 80 feet lower. The place first visited is on the 200-foot level or the Godiva tunnel level, where the contact is sharp and vertical or somewhat overhanging. The rhyolite is clayey and contains much fine-grained pyrite and gypsum; it adjoins a mass of limestone detritus, the coarse fragments of which are distinctly oxidized. There has been little mineralization, and no ore appears on the contact, but a little ore was found in the fractured limestone about 25 feet from the contact.

On the 600-foot level a dikelike mass or pipe of fragmental rhyolite appears in the limestone. The contact with the rhyolite flow is thought to be exposed on this level, but little of the rhyolite is actually seen.

From the 500-foot level there is a connection with the Tetro shaft, 1,300 feet to the west, and by ascending this for 200 feet the old, now caved Tetro tunnel is reached. Here a sharp contact is shown between clayey rhyolite and an unmistakable talus slope of limestone. The angular and unaltered fragments are from a few inches to a few feet in diameter. The spaces between the fragments are in part open, in part cemented by calcite. There is no ore in the vicinity, but in assaying the limestone along the contact Mr. Tetro obtained small quantities of silver. The contact is vertical or dips into the hill—that is, to the south; by plotting it on the map at a distance of 275 feet from the portal it will be seen that the contact is nearly vertical from the surface. The limestone slope above is very steep, and it is possible that these steep contacts represent limestone cliffs against which the rhyolite flowed. It is likely, however, that some late movement has taken place upon the contact.

The presence of hydrothermal effects along the contact of rhyolite and limestone has been mentioned by Tower and Smith,[1] who also note the occurrence of ore fragments in the limestone talus underneath the rhyolite and the abrupt termination of the ore at the contact. In spite of careful examination of all available localities it has not been possible to verify the last two statements, and the writer is forced to believe that they were based on the occurrence of a little ore in the limestone in the Godiva away from the contact and not in the talus but in fractured rock.

In the Yankee tunnel the contact of rhyolite and limestone is also intersected, 300 feet from the portal. Near the contact some limonite was noted, suggesting a slight mineralization. The only other evidence bearing upon the relation of the rhyolite to the ore was discovered in the Eureka Hill mine. On the 200-foot level about 430 feet north of the shaft the drift crosses an old depression which lies 125 feet below the present surface and 80 feet below Eureka Gulch but a few hundred feet to the south of it. The depth of the depression below the drift is not known; its width is about 125 feet. It contains abundant boulders of rhyolite and limestone, in part well rounded. According to Mr. G. W. Riter and Mr. Charles Weissbaker, respectively manager and superintendent of the mine for many years, the wash contained in places float of ore, also some "volcanic ash" and bones of animals.

This old channel of Eureka Gulch is therefore of postrhyolite age, as shown by the rounded fragments of rhyolite which it contains. From the configuration of the rhyolite it is also evident that the volcanic flow must have completely filled the narrow outlet of Eureka Gulch, and that this filling must have been eroded before the accumulations in the channel shown in level 2 of the Eureka Hill mine could have been deposited. On the other hand, the detrital channel is clearly of

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 749.

considerable age and may belong to the latest Tertiary or the early Quaternary.

The evidence then shows that the rhyolite was in place at the time of the mineralization, and it is evident that the fissures in which the ore was deposited failed to penetrate the clayey and tuffaceous lower layers of that rock. It is surprising that no extensive and rich deposits have been found underneath the impermeable cover of the rhyolite, but this is perhaps explained by the exceedingly strong selective action of the solutions in favor of the limestone and dolomite. It is also probable that the depositing solutions had no great volume but closely followed the paths prescribed by the open fractures. This is, indeed, clearly indicated by the absence of mineralization in the productive part of the sedimentary area except along certain well-defined lines, represented by the four great vein-zones.

GENESIS OF THE ORE DEPOSITS.

PRINCIPAL FEATURES OF DEPOSITS.

The ore deposits of the Tintic district have been formed by replacement and filling along fractures. In the monzonite area, where the deposition seems to have had its inception, these fractures are numerous and generally simple, trending from north to northeast. In the sedimentary rocks the main fractures, which in several places connect with those in the monzonite, generally trend north along four principal lines, but the deposition has been much more complex, for ores have been formed along fractures of all kinds and along stratification planes.

Throughout the district the characteristic gangue minerals are barite and quartz, the latter developed as replacement jasperoid or as filling and at many places clearly consisting of recrystallized gelatinous silica. The chief ore minerals are enargite and galena; in subordinate amounts are pyrite, zinc blende, tetrahedrite, an unknown bismuth mineral, and others. The lead shoots are concentrated in the northern part of the district; the copper shoots, accompanied with much barite, lie chiefly in the southern sedimentary area.

In the igneous area enargite and galena occur together at many places, but the economic importance of the ores is small. In the igneous area there has been much sericitization and much deposition of pyrite; in the sedimentary area silicification has been the only metasomatic process. The elements of the primary deposits comprise lead, copper, zinc, bismuth, gold, silver, arsenic, antimony, potassium, barium, silicon, oxygen, and sulphur.

There is a general absence of certain constituents characteristic of deep-seated deposits, such as minerals containing boron, fluorine, and phosphorus, also of all heavy silicates, pyrrhotite, magnetite, and ilmenite. No zeolites are found, and a number of metals such as tellurium, selenium, molybdenum, tungsten, and rare earths are absent. There are practically no calcium minerals, except dolomite and calcite of late or postmineral age, clearly derived from the limestone. The relative scarcity of pyrite and zinc blende in the limestone area is also noteworthy.

Physiographic considerations lead to the conclusion that the present surface is not more than about 1,000 to 2,000 feet below the surface that existed at the time of ore deposition, and that therefore the deposits were formed at relatively slight depth below the surface and not at excessively high temperature and pressure. This conclusion is confirmed by the discovery that in the northern part of the district a large part of the jasperoid and quartz was deposited as gelatinous silica.

That the ores were formed by aqueous solutions is so evident that discussion of this question is needless. To prove the temperature of the depositing waters, however, is less easy. No distinctive high-temperature minerals are present except possibly enargite, as to whose stability limits and mode of formation little definite information is available. So far as known it is never formed by cold, descending waters. The silicification and the deposition of quartz, barite, galena, zinc blende, argentite, and pyrite are possible at temperatures considerably below 100° C.—in fact, some of the deposits in the outlying parts of the district and the abnormal ore of the Gem channel in the Gemini mine bear distinct evidence of having been formed at temperatures below 100° C.

If, nevertheless, it is believed that the normal ores were generally formed at temperatures ranging from 100° to about 300° C., this belief rests more securely on geologic than on mineralogic evidence. It is thought that the solutions gradually became cooler as they pene-

trated into the sediments northward. The progressive change northward, copper ores giving place to lead ores and the grains and crystals of the quartz aggregates perceptibly decreasing in size, gives support to this belief. The absence of marcasite and the abundance of pyrite and its common octahedral form suggest higher temperatures in the monzonite than normal ground water would be expected to have. The general similarity of the veins to countless others in the Cordilleran region, many of which, it has been proved, were deposited by hot solutions, of course adds to the strength of the argument. The widespread sericitic and pyritic alteration of the monzonite proves that it was extensively permeated by solutions containing hydrogen sulphide.

GEOLOGIC EVIDENCE.

The strongest evidence as to genesis is really geologic. The deposits were formed, probably about the middle of the Tertiary period, in the interior of a huge volcanic pile in which the temperature would naturally be above normal. They were formed in or near a large body of hot monzonite, intruded as the last phase of volcanic activity, and under a thick blanket of lavas which also heated the underlying rocks.

On the other hand, the agencies that formed the deposits ceased to act long ago, as is indicated by the great degree of oxidation, as well as by physiographic evidence of débris fans and deeply buried stream beds, containing fragments of ore (p. 181). There is little reason to doubt that the deposition was completed before the end of the Tertiary period.[1]

These facts indicate that the ore deposits were formed within a relatively short epoch, just after the volcanic activity had ceased, and were therefore intimately connected with igneous phenomena. The limestone contains abundant fractures. Many of them are much older than the deposits, and some are distinctly more recent, but these, though affording excellent passageways for groundwater, contain no metallic minerals and no quartz but are at most cemented by calcite. This proves conclusively that the deposits were not formed of material extracted by the general circulating ground water from the sedimentary rocks.

DEPOSITING SOLUTIONS.

It is scarcely possible that the vast amounts of silica deposited were extracted from the sedimentary rocks. Tests for barium in these rocks have proved negative, consequently the source of both silica and barite must be sought elsewhere. The gangue and ore minerals are identical in monzonite and in limestone. All this tends with cumulative effect toward proof of the genetic connection of the deposits with the monzonite.

It is therefore believed that the depositing solutions were hot waters ascending in the monzonite on a fissure system formed very soon after its consolidation, while the rock was still hot. The ultimate origin of these waters can not be proved from the evidence available, but it is believed that they were, in part, at least, of magmatic origin, and that the precious metals, the lead and the copper, came from the magma. It is not impossible that some of the silica and the barium were leached from the monzonite, but there is no definite evidence of it. In fact, during the general alteration of the monzonite little silica appears to have been lost, and in part the rock has certainly been silicified.

The depositing solutions were then probably hot waters rich in silica, hydrogen sulphide, and various metallic sulphides. They also contained carbon dioxide. The extensive sericitization in the monzonite suggests that they may also have contained potassium. In the monzonite the heat was considerable, and comparatively little galena or enargite was deposited, the ore bodies consisting chiefly of quartz and pyrite. As the waters ascended, their circulation was in part impeded by overlying clayey and tuffaceous volcanic rocks, and they were forced northward horizontally along certain open passageways; they deposited their copper minerals first and then the lead minerals in successively cooler zones, until their silica and their metallic content became exhausted. At the same time they became enormously enriched in carbonates

[1] The volcanic eruptions that preceded ore deposition were later than Eocene sedimentation, as shown on p. 104. The eruptions antedated the upheaval of the Basin Ranges. On the other hand, lake beds of Pliocene age in the vicinity of Montpelier, Idaho, just north of the Utah boundary, are distinctly later than the Basin Range uplift, which is therefore assigned to Oligocene and Miocene time. As the ore deposits are believed to have been formed as a final expression of igneous activity, they were presumably formed before the Basin Range uplift, but as the waning stages of volcanism may have been of long duration the time of ore deposition can not be sharply fixed. If it was in progress after the uplift had begun it had ceased before erosion had advanced enough to remove much of the cover of volcanic rocks and thereby to allow the solutions to reach the surface.—G. F. L.

of magnesium and calcium. Dolomite, being less soluble, was deposited in fractures surrounding the ore zone. In the peripheral parts of the district, dolomite and calcite, with some galena and zinc blende and only minor amounts of quartz, were the only minerals deposited. The order of deposition, with respect to the monzonite contact and the relations of the different minerals to one another, are shown in figure 24.

The relations of the solutions to the igneous rocks are most interesting (p. 180). The porous monzonite was easily penetrated, but the lower tuffaceous beds of rhyolite and latite-andesite proved almost entirely impermeable except for a little hydrogen sulphide which produced an impregnation of pyrite in the lower part of these rocks.

The Swansea rhyolite porphyry was attacked in places, but wherever this rock or monzonite porphyry or rhyolite occurred as dikes in the sedimentary rocks the selective activity of the solutions favored the limestones to so great a degree that practically no ore was formed in the igneous rocks, though the surrounding limestone or dolomite may have been entirely replaced by ore. At most, the rock became altered by the development of sericite, calcite, and pyrite.

FUTURE OF THE DISTRICT.

Prospecting and development at Tintic have always been difficult and expensive, for the ore is confined to certain zones of deposition separated by long stretches of barren ground, and in each zone the ore bodies may be disposed without much regularity or continuity. The latest great developments have been in the Iron Blossom zone, and at present the more important explorations are being directed northward from the Gemini and Chief mines.

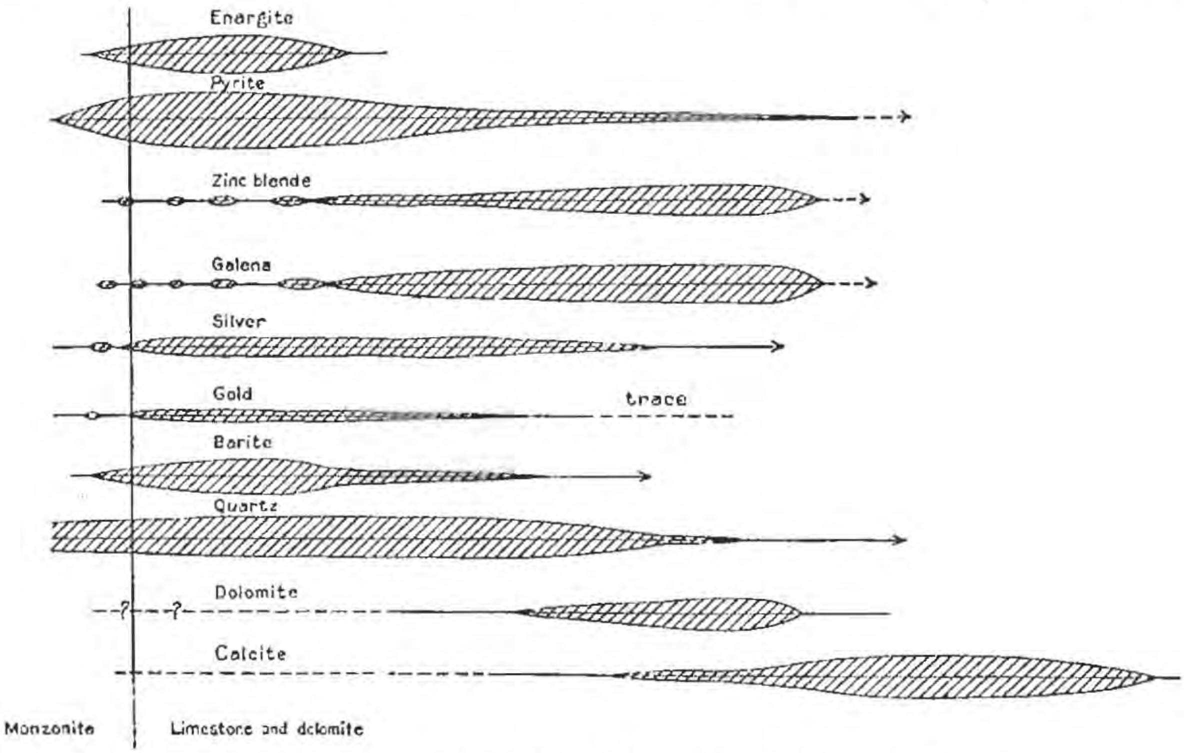


FIGURE 24.—Diagram showing relations of ore and gangue minerals to monzonite contact.

All the valuable ore zones between the Gemini and the Iron Blossom have probably been discovered. West of the Gemini zone there is little encouragement, the unfavorable formations soon giving place to the still more unfavorable quartzite. The character of mineralization shown at a few places in the workings of this area indicates that the solutions were weak, cooled, and largely depleted of their metal content. Extensive crosscuts have been driven in the region west of the

Eureka Hill and Centennial mines, without success. An extension of the Gemini zone south of the Centennial mine, which at one time appeared very probable, seems to have been definitely disproved by the explorations in the Opex mine.

The exploration northward from the Gemini mine in the deep levels seems promising, and new ore bodies will doubtless be found here. It is possible that in these deep levels below the water level the Gemini ore zone will be found to continue northward toward the Paxman shaft and perhaps toward the silicified areas north of Packard Peak. If ore is found here, especially primary sulphide ore, it will probably be rather low in silver. The connection of the Grand Central with the Centennial Eureka mine is also established, and hence the path followed by the solutions from the Mammoth to the Gemini ore zone is known. It is unlikely that in the southern part of the Mammoth zone many new ore bodies will be found by lateral exploration, except perhaps in the northeastward-trending fracture system of the Ajax and Gold Chain region. The interval between the Mammoth and the Godiva zone has been explored, with no success. In the long Sioux Ajax tunnel no mineral-bearing fissures were discovered, and explorations for 1,800 feet to the northeast of the Eagle and Blue Bell shaft have exposed very little evidence of mineralization. On the other hand, the deep workings in the Eagle and Blue Bell and Chief mines are encouraging, and the area north of the Chief mine and north of the Eureka town site offers some promise of ore in depth. In this area there is some evidence of mineralization on the surface near the Paxman mine, but no ore bodies have been found near the surface. It is likely that the ore, if present, will be found at a considerable depth.

The north end of the Godiva zone, where the limestone sinks below the rhyolite, merits more exploration than has been given to it, even if the silver content of the galena is lower here than elsewhere.

The Iron Blossom zone still contains large bodies of low-grade ore, and lateral exploration has disclosed several parallel veins, but they are not as valuable as the main shoot. The fissure veins in the southern parts of the Godiva and Iron Blossom zones have not proved very remunerative. North of the Beck Tunnel mine much effort has been expended in attempting to find the northerly continuation of the ore bodies. Probably no large ore bodies exist here, for the solutions seem to have been diverted on cross fractures, close to the Beck shaft, to the Godiva zone. On the other hand, little exploration has been undertaken to the east below the rhyolite, and it is possible that some of the solutions were diverted in this direction.

There is, in fact, room for an easterly ore zone east of the Iron Blossom zone, underneath the volcanic rocks, though the developments so far undertaken from the Iron Blossom zone have not been encouraging. The future of the East Tintic district is discussed on pages 253–254.

Exploration in depth in the monzonite area has been retarded by the high level and great volume of the water. If, as proposed, this area is unwatered by a tunnel from Goshen Valley a considerable number of veins will doubtless be found, some of which may well prove remunerative. The tunnel would have an elevation of about 5,000 feet at the portal and, with a grade of 1:300, would strike the Sunbeam mine about 1,440 feet below the croppings.

On the other hand, exploration in depth in the sedimentary area has been facilitated by the deep water level. The proposed tunnel would strike mines in the sedimentary zone high above the water level and would therefore help mainly by lessening the height to which the water would have to be pumped.

Exploration below known ore bodies has not been universally successful in the district. Few ore bodies have been found in depth in the Iron Blossom and Godiva zones. The Mammoth has low-grade ore close to the water level, and in the Eagle and Blue Bell and Chief mines the ore bodies have recently been found to extend below the water level. Along the Gemini zone very encouraging results have been obtained to a depth of 250 feet below water level, but it is manifestly more than could be expected of a single mine to handle the great amount of water, for any one deep mine in this vicinity will probably drain most of the water in the neighboring properties.

If the hypothesis outlined above (p. 183) as to the lateral movement of the depositing solutions from the monzonite area northward is true, it is not likely that the ore will continue

indefinitely in depth. The ore bodies in the deep levels of the Gemini and Chief mines are probably caused by the damming influence of the impermeable rhyolite blanket, which here rests on the limestone at comparatively low altitudes. The solutions could not rise freely toward the surface, hence under the impelling force with which they ascended in the hot monzonite they would be guided northward in the upper shattered zone of the limestone until, cooled and mingled with surface waters, they had deposited their metallic load.

The steady and long-continued production of the district has in part been caused by the discovery of new ore bodies, but in large part also by successive workings of the same ore bodies. At first only the richest ores were extracted. Later, when the charges for treatment declined, the old stopes, most of them still open in the hard jasperoid or limestone, were reworked and ore of lower grades taken out. At the present time there are in many of the mines large reserves of ore of a gross value of $5 to $10 a ton, for which a cheap and effective process of reduction is now sought.

The probabilities favor the view that the mineralization will be found to continue to great depths in the monzonite area, for the solutions appear to have ascended in that vicinity. Owing to the indicated lateral movement of the solutions in the sedimentary area it is possible that in some mines in this, the main part of the district, the mineralization will be found to cease before great depth is attained.

MINES IN THE SEDIMENTARY FORMATIONS.

GEMINI AND RIDGE AND VALLEY MINES.[1]

Location.—The mining properties owned by the Gemini and the Ridge and Valley mining companies are under one management and are operated from the Gemini shaft. They constitute one of the most important mines of the district and one which, though having had its greatest production in the earlier years of the district, is far from exhausted. The claims extend in a general northerly direction and lie north and south of Eureka Creek, at the west edge of the town of Eureka. They cover a total distance of 2½ miles, but the principal producing section lies north of the shaft.

The mine has for many years been operated by members of the McChrystal family. Much information has been obtained from Messrs. Jackson C. and John H. McChrystal.

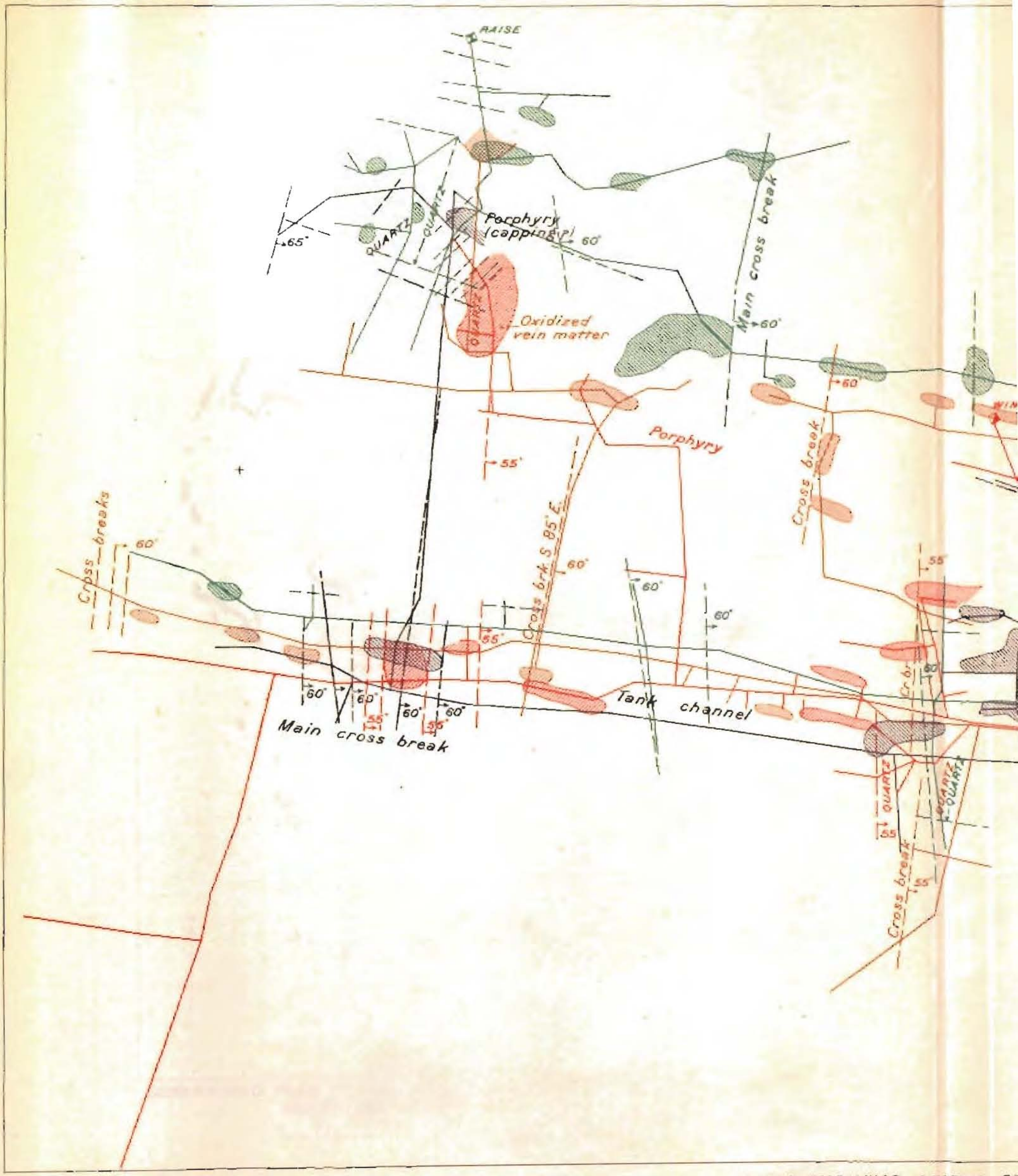
Development.—The Gemini vertical shaft is sunk on the north bank of Eureka Creek, about 100 feet above it, at an altitude of 6,467 feet. Its depth is 1,650 feet, the lowest level, No. 16, being turned at a depth of 1,644 feet. The levels extend mainly a little east of north, level 16 having reached about 1,700 feet north of the shaft. The developments south of the shaft reach to the Bullion Beck line, a distance of about 700 feet. Levels are turned at 100-foot intervals, but the upper levels are not worked now. On level 14, which is 1,444 feet below the collar, a long crosscut eastward connects with level 16 of the Chief mine. From level 16 a winze 300 feet deep has been sunk on the Gem channel to a few feet below level 19, which is thus the deepest level in the mine. Since 1911 most of the work has been done on levels 14, 15, and 16.

Production.—The total production of the Gemini mine has never been made public. Up to November 13, 1914, $2,355,000 had been paid in dividends, so that it may be fair to assume that the value of the total output is about $10,000,000. The production of the Ridge and Valley mine, which includes the most northerly ore bodies, has so far been small, and the ore tonnage has been less than that of the Gemini mine.

A little gold and copper and zinc are credited to the mine, but the principal output is in lead and silver, and it is probably not an exaggeration to say that all the ore extracted has assayed on the average about 10 per cent of lead and 40 ounces of silver to the ton. According to unofficial statements the annual ore production during the last few years has approached 25,000 tons.

Water.—The water level was found at level 16, at an altitude of 4,813 feet. After a winze had been sunk to level 19 the water was held there by electric pumps lifting 300 gallons a minute, or 432,000 gallons in 24 hours. The water is now stationary at level 16 at the winze, at an altitude of 4,835 feet. About 20,000 gallons a day of seepage water is dumped in

[1] Tower, G. W., jr., and Smith, G. O., op. cit., pp. 734-737. Heikes, V. C., [Utah mine reports]: U. S. Geol. Survey Mineral Resources, 1905-1913.



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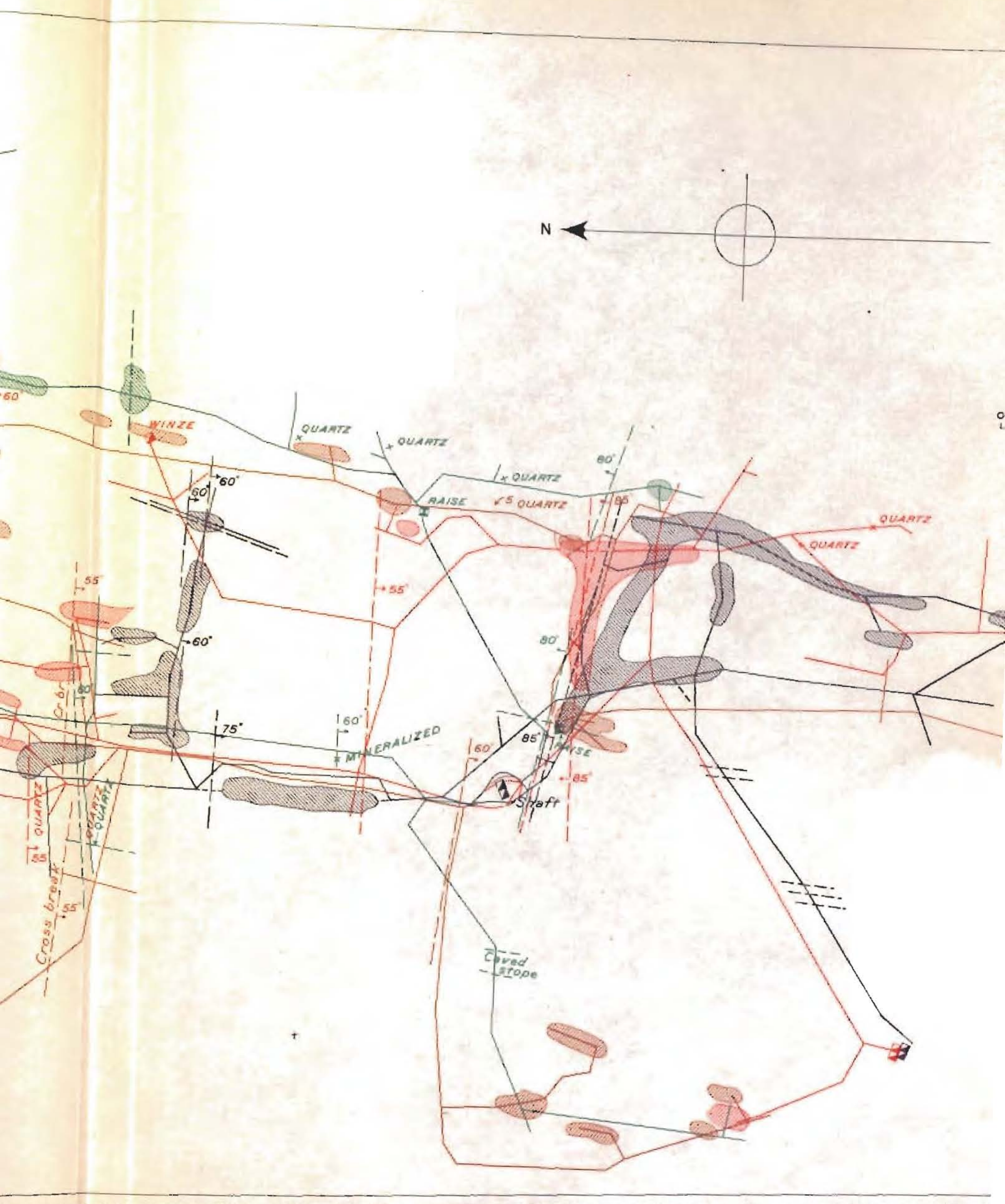
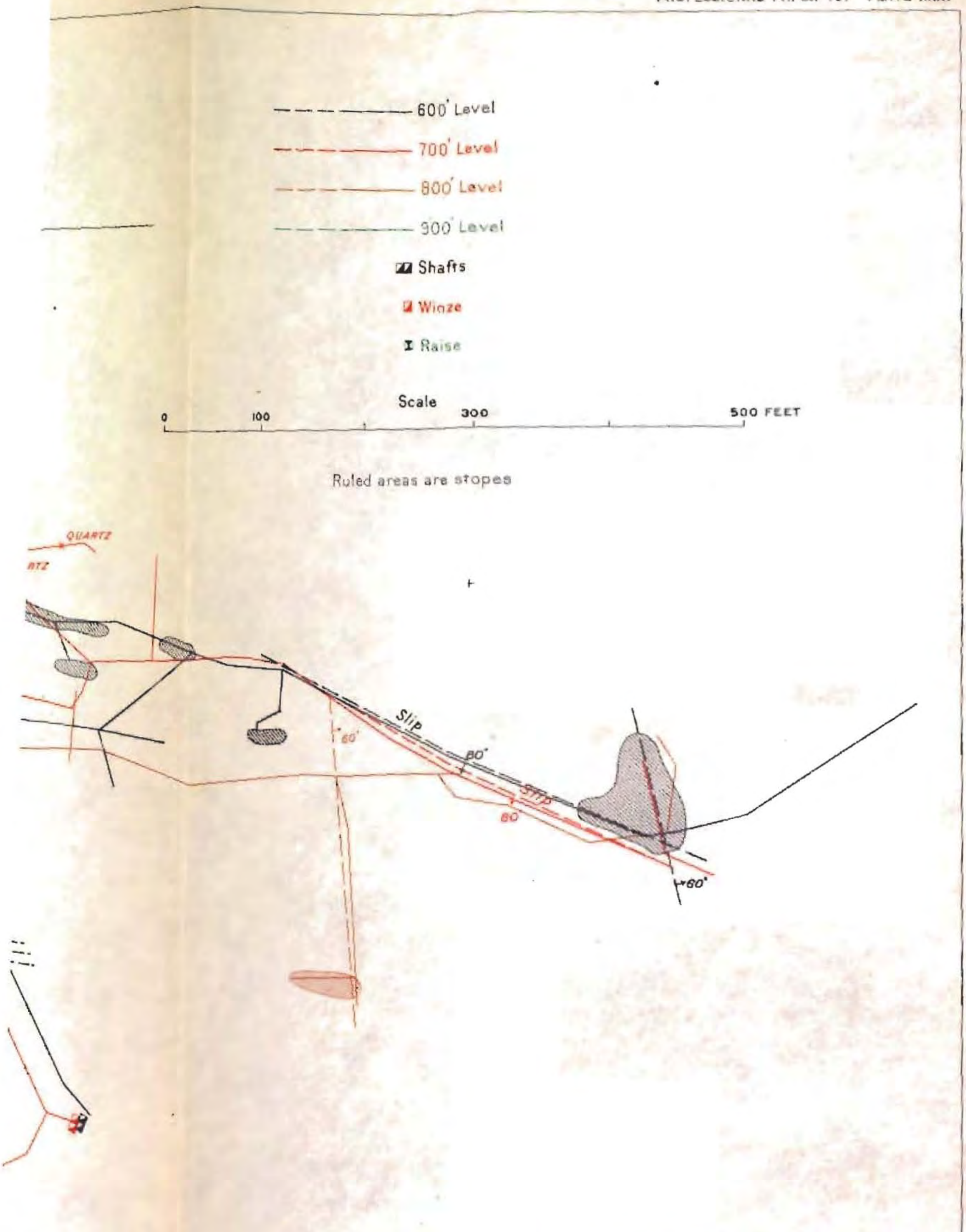
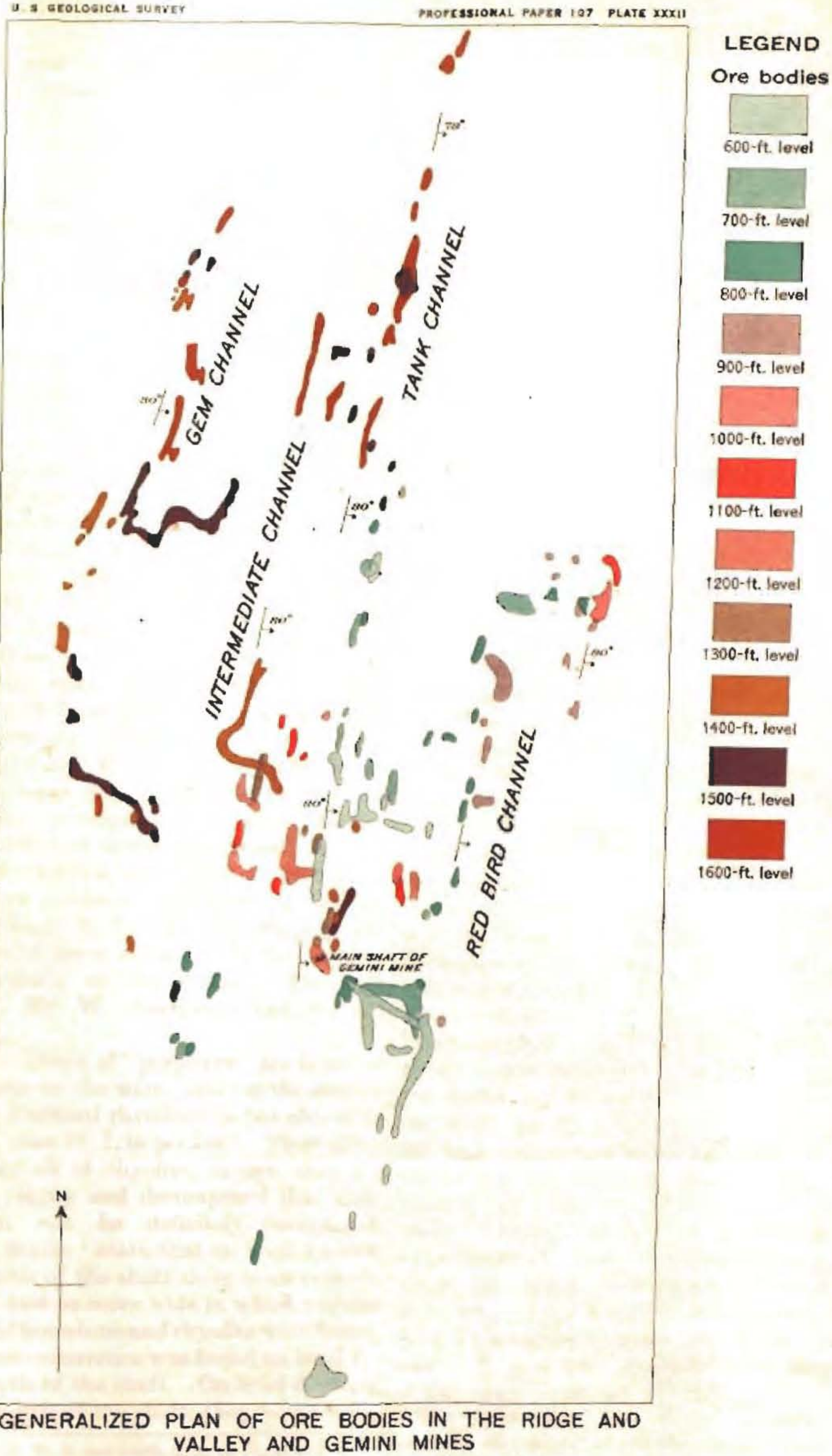


VING DRIFTS, CROSSCUTS, AND PRINCIPAL ORE BODIES ON LEVELS Nos. 6, 7, 8, AND 9 IN THE GI



AND 9 IN THE GEMINI MINE

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



GENERALIZED PLAN OF ORE BODIES IN THE RIDGE AND VALLEY AND GEMINI MINES

this winze without affecting the water level. Most of the levels are entirely dry, but some water is met in the Gem or westerly channel on levels 14 and 15, so that levels 13 to 16 are very wet in this part of the mine.

Geology.—Most of the workings are in the Bluebell dolomite, which consists of heavy beds of dark-gray, rather fine grained rock. On the surface the Bluebell dolomite occupies an area about 1,200 feet wide from east to west. In the northern part of the mine and on the lower levels the strike is N. 20° W. and the average dip is 78°–82° E. On the surface at the shaft the strike is nearly north, and farther north about N. 8° E., so that the underground observations indicate an easterly twist. Exact measurements of dip and strike are possible only at a few places in the mines.

The ore-bearing fractures extend a little east of north, closely following the stratification. Much more prominent than these, however, is a strong system of easterly "cross breaks"; these fractures are observed in all parts of the mine and are more abundant than in the Bullion Beck mine on the south. Most of them dip 55°–70° S. and strike from N. 70° E. to S. 70° E. Beginning at the shaft, the cross breaks are spaced 100 or 200 feet apart. The so-called "main cross break" lies about 450 feet north of the shaft on level 15. In the extreme north end of the mine a few fractures intersect the trend of the ore bodies, striking S. 50° E. and dipping 75° SW. None of these cross breaks find expression by faulting on the surface. Fractures striking N. 30° W. also occur but are not common.

Rhyolite.—Dikes of "porphyry" are found at several places in the mine, and on the surface the flow of Packard rhyolite reaches almost to the shaft. (See Pl. I, in pocket.) These dikes are probably all of rhyolite, though they are usually so clayey and decomposed that their nature can not be definitely recognized. Tower and Smith[1] state that on level 3 about 200 feet north of the shaft there is an easterly fracture 10 feet or more wide in which angular fragments of limestone and rhyolite were found, and a similar occurrence was found on level 11, 300 feet north of the shaft, On level 6, about 1,000 feet south of the shaft, they found a 10-foot dike of rhyolite striking northeast and dipping 85° SE. They also found in the workings 300 feet east of the shaft on levels 6, 7, and 8 a definite northward-trending contact between rhyolite and limestone and were inclined to regard the contact as a talus slope, because the two rocks are separated by a zone of broken material 10 to 20 feet wide. The present writer examined two of these places on levels 6 and 7, but considers the evidence of talus doubtful. During the present examination rhyolite was found on level 16, 1,300 feet north of the shaft, adjoining ore and limestone in the Tank channel. The soft clayey material, which contains some pyrite and gypsum, is probably rhyolite. It is about 8 feet thick.

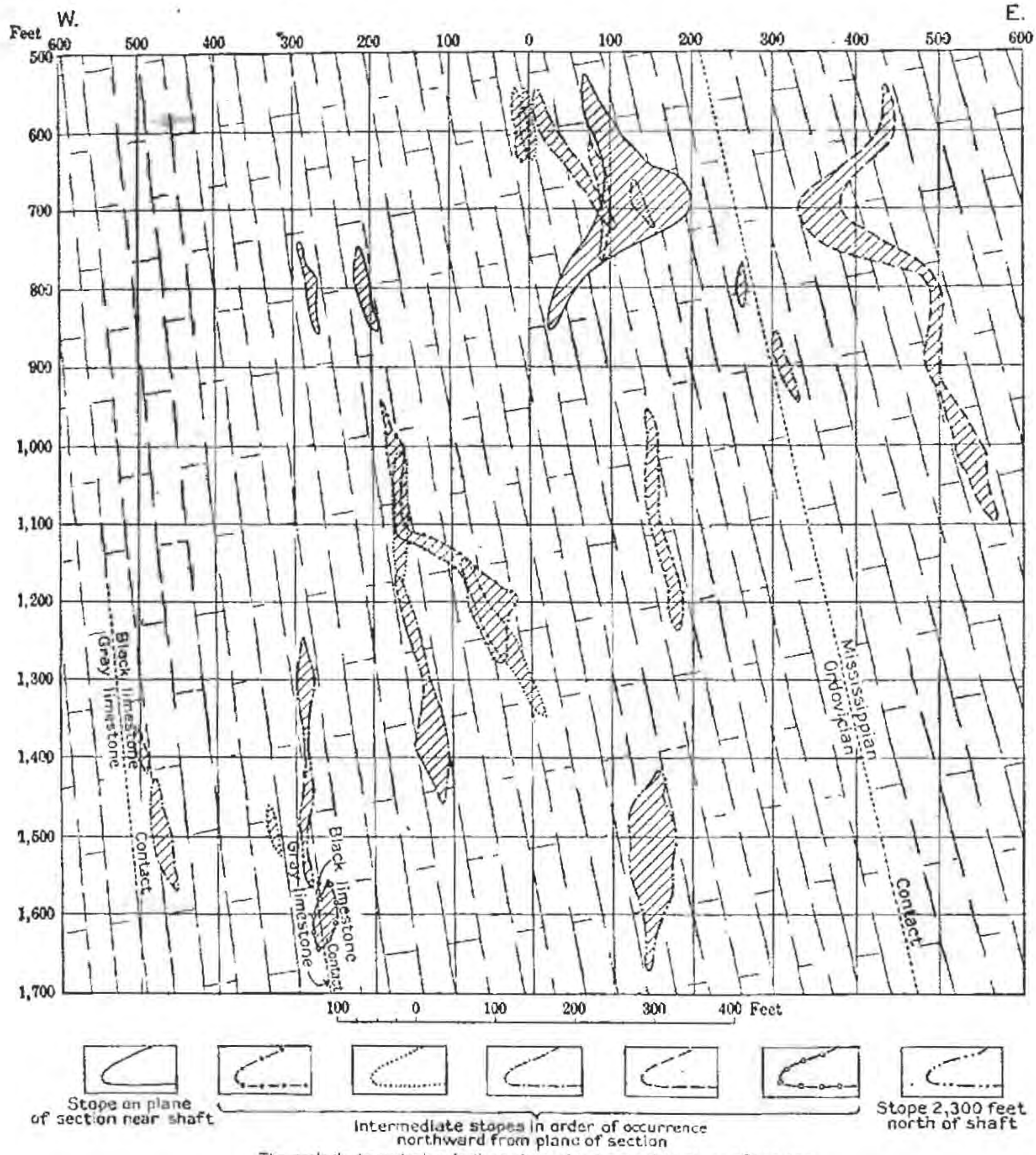
Ore bodies.—No outcrops of ore are seen at the surface. Close to the shaft is an outcrop of altered and rusty limestone which is considered to represent the Tank channel. Farther north, near the Ridge and Valley shaft, some silicified limestone is observed at the surface. The only ore found above level 4 was in small bunches following N. 5°–10° W. fractures. The first large ore body was opened on level 5, east of the shaft, and other bodies have been found on all lower levels down to the greatest depth attained, or 1,900 feet. (See Pl. XXXII.)

As shown on Plate XXXI the ore occurs along four distinct and parallel lines which closely follow the stratification, striking N. 15° E. and dipping 80° E.; these are from west to east the Gem, Intermediate, Tank, and Red Bird channels, and for the most part they lie within a width from east to west of 750 feet. The ore bodies are irregularly distributed as lenses or pods along these lines, as is well shown in the composite cross section (fig. 25). The upper ore bodies were found mainly near the shaft, but in the lower levels a tendency has been shown to a northerly pitch, so that the present ore bodies on the Tank and Gem channels lie 1,000 to 1,700 feet north of the shaft. Although the ore bodies thus in the main follow the beds, there are many places where they break away along fissures; where they take to the easterly cross breaks they form a connection between two of the "channels." This is well illustrated on a diagram of the upper levels (Pl. XXXI).

The Red Bird and Tank channels are strongly developed on levels 6 and 7 near the

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 737.

shaft. The ore bodies are as much as 30 feet wide and continuous for several hundred feet; they begin on the Red Bird south of the shaft, then take a cross break and go over to the Tank, north of the shaft on the Intermediate and Tank channels, but some ore shoots have also been found on the Red Bird channel 900 feet north-northeast of the shaft. On levels 14, 15,



The geologic boundaries indicated are about normal to plane of section

FIGURE 25.—Composite cross section of the Gemini mine, showing form of ore bodies.

which they follow for 1,000 feet as lenses separated by barren stretches. On levels 8 and 9 on the Red Bird isolated ore bodies continue as far north as on levels 6 and 7. On levels 10 to 13 the ore bodies lie mainly for 500 feet and 16 most of the ore bodies lie from 1,000 to 2,000 feet north of the shaft on the Tank and Intermediate channels and pitch to the north. They range in width from a few feet up to 35 feet and at many places turn and follow cross

breaks. Some of them are continuous for 200 feet, but many of the smaller bodies are pipes with elliptical cross section. At one place on level 14 three such pipes, each about 6 feet in diameter and surrounded by limestone, were noted in triangular arrangement within a circle of 25 feet. The Red Bird channel contains few ore bodies on level 14, the lowest level on which it has thus far been opened.

The Gem channel first appears in the mine on level 13, although it has been mined at considerable higher levels in the Bullion Beck and Eureka Hill mines. In this mine the Gem channel presents some very peculiar characteristics. The ore began along a break following the bedding about 1,300 feet north of the shaft above level 13, and from this point the ore was followed down in lenses and pipes to level 19. The approximate outline of this shoot, in longitudinal projection, is shown in figure 26. The ore ranges from a few feet to 50 feet in width and is very irregular, though as a whole parallel to the fissure, which here trends N. 20° E. On levels 15 and 16 the ore bodies lie nearer to the shaft and in part connect on cross breaks with the Intermediate channel. The Gem ore bodies lie in a dark-colored dolomite, which along the channel line is irregularly converted to a black jasperoid. The ore is oxidized only in part, though this partial oxidation descends below the water level at about 1,650 feet below the collar of the shaft. The Gem channel is very wet for 200 feet above the water level, but in other parts of the mine the ore bodies are nearly dry.

Ore supply.—Like most of the other mines of the Tintic district, the Gemini mine rarely has large bodies of ore opened at any one time. Nevertheless it has been a steady producer for many years. The occurrence of the ore in more or less isolated pods and pipes renders a great deal of intelligent development work necessary, and an examination of the mine maps suggests that the possibilities are far from being exhausted. Moreover, many of the ore bodies have been worked twice. In the earlier years only the richer parts were extracted, and there remained much poorer ore that would yield a profit when conditions of smelting and transportation improved. For instance, in 1914 an old 8-foot stope on the Intermediate channel on level 14 was re-

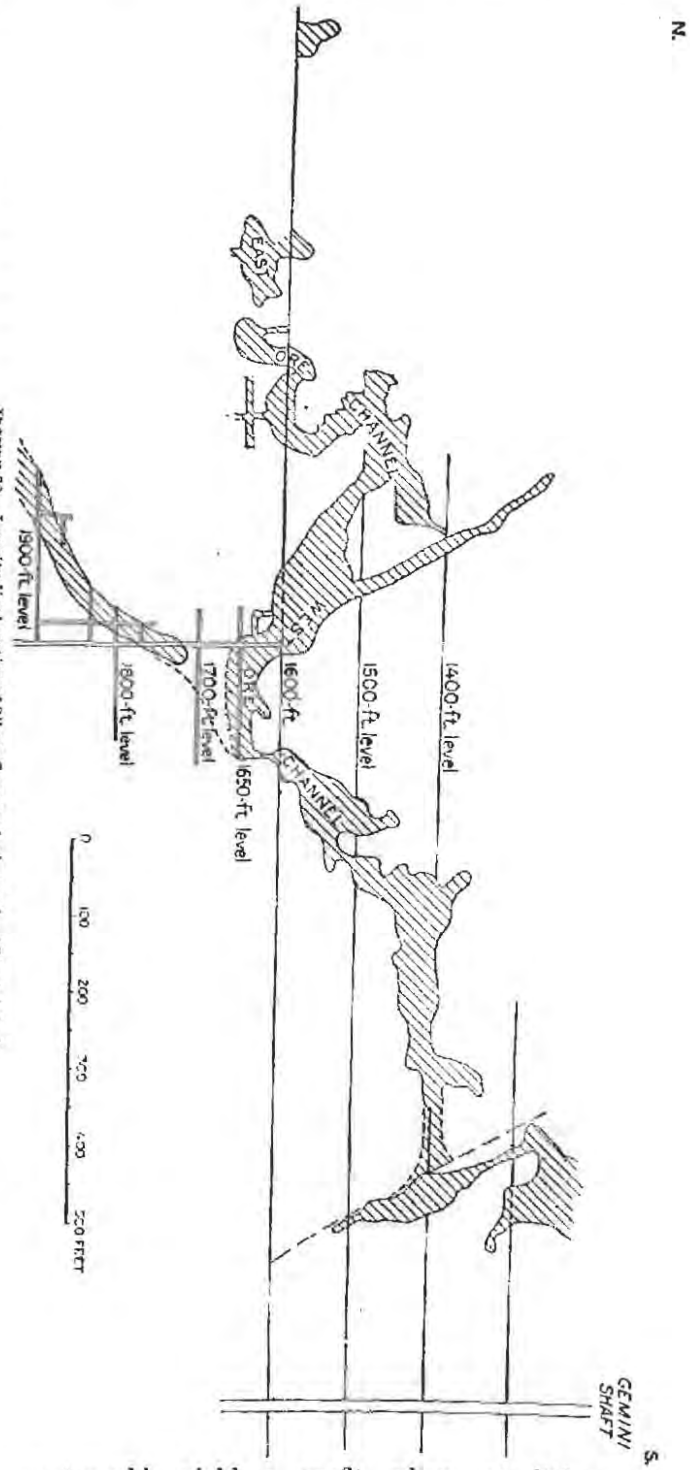


FIGURE 26.—Longitudinal section of Silver Gem ore body north of Gemini shaft.

opened and it was found that only the oxidized soft ore had been removed which contained 30 per cent of lead and 20 ounces of silver to the ton; adjoining this was a body of black jasperoid with galena, several feet in width, which at the later date proved profitable to extract.

Ores and minerals.—The ore bodies occur as lenses, pods, or pipes along the fracture lines, most of which trend N. 10°–20° E. The thickness of the ore ranges from a foot or two up to 30 feet or more, rarely 50 feet. The mineralization along the fracture lines is marked by the irregular replacement of dolomite by gray or bluish jasperoid which connects the ore pods along the strike of the fracture, though this silicification is not absolutely continuous. In many places the silicification extends a few feet beyond the ore, and the silicified rock is accompanied by sparsely disseminated galena and zinc blende.

Smelter analyses of Gemini ores.

	1	2	3	4	5	6
Lead........per cent..	5.1	7.65	14	11.65	11	22
Iron........do....	4.6	3.95	4	3.55	4.5	3–4
Zinc........do....	2.6	2.30	10	2.6	3.0	3–6
Copper........do....	....	....	....	....	1.0	....
Sulphur........do....	1.0	1.15	.65	4.65	1.5	1–6
Insoluble........do....	65.2	54.40	42	62.4	63	....
Silver........ounces to the ton..	15.0	57.5	193	115	42	200

1. Low-grade ore shipped from dump.
2. Lead ore from level 14.
3. Lead and silver chloride ore from Red Bird channel.
4. Rich sulphide ore in pipe on level 14 extending up from winze 19, Gem channel.
5. Rich sulphide ore in winze stope on level 16½, Gem channel.
6. Rich sulphide ore from Gem channel on level 17.

The Gemini ores were oxidized in large part down to the water level, or about 1,650 feet below the collar, but in the deeper levels the oxidation is only partial and much galena is seen on levels 14, 15, and 16. The ores are in the main siliceous lead ores. The gangue is fine-grained bluish gray flinty jasperoid, replacing dolomite and usually containing small plates of barite.

The ore of lower grades that could be mined in 1911 had a minimum value at the mine of about $10 a ton and contained 14 to 15 ounces silver to the ton and 4 to 6 per cent of lead.

Galena and cerusite, with more or less anglesite, are the principal lead minerals. The average galena contains 30 to 40 ounces of silver to the ton. Higher contents usually indicate admixed silver chloride or rich sulphosalts, such as pearceite.

Some lead stopes from the Intermediate channel on level 14, in large part oxidized, yielded 30 per cent of lead and 15 to 20 ounces of silver to the ton. In the same vicinity were chloride ores with 6 to 7 per cent of lead and 75 ounces of silver. Copper stains are not uncommon and are derived from the oxidation of tetrahedrite, pearceite, or more rarely enargite. Only one specimen of enargite was found; it came from level 19.

Zinc blende is found in the primary unoxidized ores, as small grains in jasperoid or as inclusions in galena. A small quantity of pyrite is generally present. Cerargyrite was abundant in the upper levels, but specimens were found even in level 17. Tower and Smith mention crusts of horn silver a quarter of an inch thick from the upper levels. Native silver is not uncommon, and wire silver with cerusite was noted in specimens from level 19—that is, 250 feet below water level.

The primary lean ore of the three easterly channels consists of blue or gray jasperoid, locally banded, in which are disseminated small grains of galena, zinc blende, and pyrite (Pl. XIX, *B*, p. 156). Cavities in this ore are coated with white fine-grained quartz, at the base of which galena is often deposited in abundance. More or less barite is present but is rarely conspicuous. The oxidized ore is a soft and honeycombed mass of silica, cerusite, anglesite, etc., with small amounts of limonite.

Some of the lead stopes are adjoined by bodies of oxidized zinc ores, some of which

have been shipped. This zinc ore usually replaces limestone outside of the silicified zone, and the material of shipping grade averages about 30 per cent of zinc.

The oxidized zinc ores have been found to some extent below level 12 and on level 13 but have for the most part been mined from levels 14 to 16, in both the Gemini and the Ridge and Valley mines. The western (Gem) channel has thus far yielded practically no zinc ore. Small pockets of high-grade ore have been found along it, but no body of promising size has been opened. The middle (Intermediate) and eastern (Tank) channels both contain considerable bodies of zinc ore and have together yielded the total amount shipped. The zinc ore as a rule forms casings around the lower parts of the lead-silver stopes, the greatest concentration being on the footwall side (fig. 23, *G*, p. 172). The ore also follows fissures and bedding planes for short distances away from the lead-silver stopes, but none has been found at any considerable distance from the lead-silver stopes.

The gray and brown types of ore were noted in several different stopes, and some black ore was seen in the lowest, on the 1,600-foot level of the Ridge and Valley mine. The fibrous botryoidal, cellular, and drusy smithsonite and the drusy calamine are said to have been widely distributed along fractures in ore now stoped out.

The ore of the Gem channel in this mine is very peculiar and suggests a sulphide enrichment. The Gem channel has been worked in this mine only below level 13, but from that level the ore bodies were continuous down to level 19. On levels 14 and 16 the ore contains mainly sulphides, partly oxidized. Similar conditions existed below the water level down to level 19, according to statements by Messrs. McChrystal, which were substantiated by examination of a suite of specimens from the lowest level.

The ore, which is described in more detail on page 177, is contained in a breccia of jasperoid and dolomite and consists of galena, zinc blende, marcasite, and pearceite (or a closely related mineral). It is rich in silver and averages in the Gem channel 15 per cent of lead and 50 ounces of silver to the ton. Analyses of separate lots of ore are given in the above table. Assays of selected pieces gave as much as 2,000 ounces of silver to the ton.

BULLION BECK MINE.

Location and development.—The Bullion Beck mine, one of the oldest in the district, lies between the Gemini and the Eureka Hill. It is now owned by the United States Mining Co. The mine has been worked from 1882 to the present time, although since 1911 the operations have been on a small scale and mainly carried on by lessees.

The mine is opened by a vertical shaft close to Eureka Gulch below the town of Eureka, at an altitude of about 6,360 feet. The depth is 1,300 feet, and a winze from the deepest level reaches 200 feet below the bottom of the shaft. The shaft and winze were dry at the time of visit. Some water came in from 100 to 1,100 feet below the surface and in 1911 a little water, probably from a pocket, was covering the deepest level.

The developments are extensive on all levels, but little work was being done in 1911 below level 5. The drifts extend about 600 feet north of the shaft and 1,200 feet south of it and connect on most levels with both adjoining mines. The total length of drifts amounts to at least 10 miles.

Production.—The production of the Bullion Beck mine has never been made public, but the total dividends paid are said to amount to $2,768,400, which is somewhat more than has been paid by the Gemini mine. If it is assumed that one-fourth or one-fifth of the gross production has been paid in dividends, the total value of the output may be estimated at $13,000,000 or $14,000,000. The total tonnage is not large, certainly not over 400,000 tons. Some gold and copper have been produced—in fact, considerably more than in the Gemini mine—but the principal metals are silver and lead. The ore has varied greatly in richness but is on the whole a siliceous lead ore probably averaging 30 ounces in silver to the ton and about 15 per cent of lead.

Geology.—The Quaternary deposits of Eureka Creek cover the outcrops of the rocks in large part, but enough is shown to indicate that the notable northeasterly fault that extends obliquely across Eureka Creek passes almost through the shaft. Drifts to the north pass into the Bluebell dolomite; the southward workings reach into the Opex dolomite and Ajax limestone, cut by several minor east-

northeasterly faults. Underground, the different formations are difficult to recognize without long and detailed study.

The strike of the beds is in general a few degrees west of north, and the dip is either vertical or very steep to the south. The influence of the strong northeasterly fault, along which the southern block has moved about 1,000 feet northeast and has become greatly fractured, is not markedly shown in the distribution of the ore bodies, and the fault itself is not conspicuous in the mine; it is probably the oldest dislocation and at the time of mineralization was completely healed. The rocks north of the shaft are fresher and harder, showing good bedding and no disturbance, but for 100 feet south of the shaft the limestone, on the upper levels at least, is greatly broken and the bedding is indistinct.

On level 13 the rock south of the shaft is hard and fresh and the disturbed ground appears on the north. From these relations it would seem probable that the fault plane dips steeply northwest.

The easterly fractures which so commonly influence the ore in the Gemini and the Eureka Hill are not conspicuously present in the Bullion Beck.

Ore bodies.—The ore bodies in general follow northerly fractures that closely or entirely coincide with the bedding planes, but these fractures are rarely marked by conspicuous displacement. In general the three principal ore zones of the Gemini, which, from west to east are called the Gem, Tank, and Red Bird channels, continue into the Bullion Beck ground and may be said to unite south of the shaft, at the same time bending to a south-southeasterly direction.

During the visit to the mine in 1911 the opportunities for studying the ore bodies were poor because many levels were inaccessible and little ore could be seen. To the north of the shaft the ore occurs more in isolated lenses or pods along the three "channels," as in the Gemini mine. The greatest ore bodies are found to the south, between the Bullion Beck and Eureka Hill shafts, and these are described in the section on the Eureka Hill mine, as the line between the two properties almost parallels the extension of the ore.

No outcrops are visible on the property. The uppermost ore bodies begin at a depth of 100 or 200 feet immediately below the detritus. The largest bodies were on levels 4, 5, and 6. In the deepest levels no large bodies have been found.

The ores follow in part northerly fractures, in part those trending N. 10° W. or N. 10° E., or more rarely northeasterly or easterly cross breaks. It is in places difficult to decide whether the ore follows the stratification planes or an obliquely intersecting fracture. North of the shaft the ore bodies occur within a distance of about 600 feet east and west, but south of the shaft, where they turn to a south-southeasterly direction, they occupy a width of only 250 feet. In this mine the two principal channels, corresponding to the Gem and the Tank of the Gemini mine, are known as the Silver Gem and Eureka Hill channels. Both of these continue into Eureka Hill and Centennial Eureka ground (fig. 28, p. 195). The greatest ore bodies lie between the two shafts and are formed by the merging of the Silver Gem and Eureka Hill channels, which here seem to follow a N. 35° W. fracture with numerous offshoots. In the lower levels the two channels are again distinct, but much of the ore is localized in chimneys. One of these chimneys, as stated by Tower and Smith,[1] lies at the north end of the Bullion Beck property and has been followed to a depth of 1,200 feet; it is about 30 feet in diameter and pitches south at an angle of 70°. In 1915 it was reported that a large body of mixed sulphide ore was being mined from the 1,300-foot level north, carrying 15 per cent of lead, 15 per cent of zinc, and 8 ounces of silver to the ton.

The ore.—The siliceous silver-lead ores of the mine were largely oxidized, but residual galena began to appear on level 4. South of the shaft the ore contains a small amount of gold, say 0.02 ounce to the ton, and a little copper ore containing some arsenic has been shipped from the Gem channel. A little zinc ore occurred on level 9, and some shipments contained as much as 10 per cent of zinc. Otherwise the mineralization is entirely similar to that of the Gemini mine.

EUREKA HILL MINE.

Location and ownership.—The Eureka Hill mine, one of the oldest and most productive mines of the Tintic district, is on the south

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 733.

side of Eureka Gulch just below the town of Eureka and almost due south of the Gemini. In 1911 work by the company had practically ceased, though the levels were still open and lessees were operating on several of the upper levels. The mine, which is owned by the estates of Justice Field, George E. Whitney, John A. Packard, Joseph Packard, and Joab Laurence, has been worked for many years under the direction of the late G. W. Riter, who kindly furnished much valuable assistance and information.

Production.—The mine has a large output to its credit, principally of silver and lead, and the beginning of its productive period dates back to 1877. The tonnage of ore is of the same order of magnitude as that of the Gemini and Bullion Beck mines but is probably larger. The total gross value of the ore may be estimated as between $10,000,000 and $15,000,000. Some copper and gold has been produced but no zinc. The tenor of the ore has varied greatly, but the average has been about 25 ounces of silver to the ton and 7 to 10 per cent of lead.

Development.—The mine is opened by a vertical shaft 1,520 feet deep and having altitude at the collar of 6,476 feet. There are about fifteen levels extending north and south and about 11 miles of development work. The lowest level now accessible is 1,100 feet below the collar. There are signs of water on the 1,500-foot level and small seepages at other places.

Geology.—The country rock of the deposit is the dark-gray or blue dense Ajax limestone (Pl. I, in pocket). Along the center of the claim runs the "creamy lime," so designated by G. W. Riter, a characteristic stratum 22 feet wide, breaking with yellowish-white color and evidently identical with the Emerald dolomite member of the Ajax limestone. To the west of this some of the workings enter the Opex dolomite. The strike of the limestone beds is N. 10°-13° W. and the dip about 87° W. No igneous rocks of any kind are found in the mine. This mine contains several small caves. One on level 3 described by Tower and Smith is said to have been filled with horizontally deposited banded quartz and lead carbonate and thus might have been filled during the primary mineralization. If so it is the only clear instance of such an occurrence in the district. Other caves are distinctly post-mineral and filled by horizon tally stratified cave earth.[1]

Level 2 at one place runs into detritus of Quaternary or Tertiary age with boulders of limestone, rhyolite, and, according to G. W. Riter, ore.

Outcrops.—The deposit shows one line of well-defined outcrops along its eastern ore zone, which follow the ridge crest leading up to the Centennial Eureka mine, at altitudes of 6,600 to 6,900 feet. These outcrops have been mined throughout their extent; the open stopes, which have a maximum width of 15 to 20 feet, are still visible. They contained an oxidized lead ore with limonite and honeycombed fine-grained quartz or jasperoid; higher up on the hill along this outcrop zone oxidized copper ores seem to prevail, also with limonite and some black manganese dioxide, in part crystallized. The copper ore contains malachite, azurite, and some arsenates. The surrounding limestone is practically unaltered. From north to south the ore body shows several small offsets to the east. Both in the lead and in the copper stopes some of these offsets contained ore.

Occurrence of the ore.—As the side line separating the Eureka Hill and Bullion Beck mines intersects the principal ore bodies it will be necessary to consider the Bullion Beck mine to some extent in this description.

The ore forms irregular podlike masses which extend along the general direction of the stratification but in places jump on cross breaks to a different set of beds. The ore undoubtedly follows fissures, which may not be strictly parallel to the stratification and which, outside of the ore bodies, are inconspicuous and do not even contain limonite or quartz. On the third level one of these fissures trends north and dips 80° W. The fact that the fissures are so inconspicuous suggests that no great premineral displacement has occurred along them, though in the absence of dikes or strata of distinctive characteristics such displacement would be difficult to detect. On the third level the well-defined fissure mentioned above shows striations dipping 10°-20° N., indicating that the movement has been partly in a horizontal

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 734.

direction. Fractures trending N. 35° W. are prominent between the Eureka Hill and Bullion Beck shafts and have no doubt produced the decided north-northwesterly trend of the ore bodies in this vicinity.

The second feature that has an important influence on the occurrence of the ore is the prevalence of "cross breaks." These are well marked, in many places persistent; some of them are open. They range in trend from north-northeast to east-northeast, but some of them strike N. 30°–35° E. and dip 65°–70° NW. One measured on the 1,100-foot level strikes N. 66° E. and dips 70° SSE. On this break were noted slickensides with striation dipping 20° NE., again indicating a prevalence of horizontal movement. The cross breaks are healed in places by calcite.

There is probably little dislocation along these cross breaks; it was thought by G. W. Riter that at one place the "creamy line" (Emerald dolomite) referred to above is faulted 15 feet to the east. South of the Eureka Hill shaft and up to the Centennial line the east-northeasterly cross breaks are numerous and prominent, and in places the ore follows them, thus connecting the several "channels." Tower and Smith state that at three places on levels 7 and 10 cross breaks were found which carried drag of ore and limestone and on which postmineral dislocation must therefore have occurred. Such occurrences were not observed during the present investigation. The northeasterly fault, which, as shown on the map (Pl. I), displaces the Emerald dolomite at a point 300 feet south of the Eureka Hill shaft, is not plainly visible underground and, like the great Eureka Creek fault, has little or no influence on the ore. This dislocation was probably completely healed before the mineralization.

Ore bodies.—The Gem, Tank, and Red Bird channels of the Gemini mine enter Bullion Beck ground, and, from a series of detached podlike ore bodies, coalesce to a large body south of the Bullion Beck shaft. Large masses of ore were mined here on levels 4, 5, and 6, and the trend is north-northwesterly. South of the Eureka Hill shaft there are again two distinct "channels," here called the Gem and Eureka Hill, and another, perhaps representing the Red Bird, begins at the Eureka Hill shaft and continues with surface outcrops up to the Centennial shaft. On the whole, the Gem channel is the most persistent, for it can be followed from the Gemini workings through the Bullion Beck, Eureka Hill, and Centennial mines. Some of the larger bodies between the shafts passed across the side line into the Bullion Beck workings on deeper levels.

The ore bodies form irregular podlike masses, which in places, especially at the south end, are rudely tabular but which rarely continue for more than a few hundred feet in depth. Figures 27–29 give a somewhat diagrammatic representation of their extent. The ore began in part at the surface south of the shaft, or immediately below the detritus,

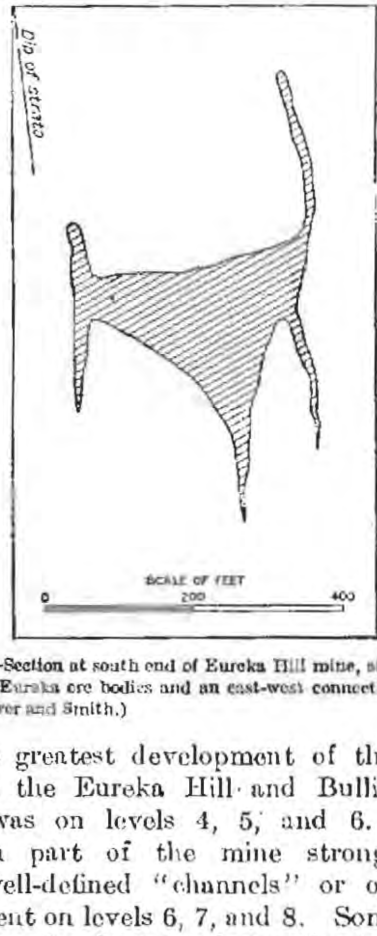


FIGURE 27.—Section at south end of Eureka Hill mine, showing Silver Gem and Eureka ore bodies and an east-west connecting ore body. (After Tower and Smith.)

and the greatest development of the bodies between the Eureka Hill and Bullion Beck shafts was on levels 4, 5, and 6. In the southern part of the mine strong bodies along well-defined "channels" or ore zones are present on levels 6, 7, and 8. Some bodies continue to level 10, but below this level there is little ore or evidence of siliceous replacement.

The largest ore bodies were found between the Bullion Beck and Eureka Hill shafts and were formed by the coalescing of the Eureka Hill and Gem channels. The Billings stope had a cross section of 100 by 100 feet and

extended down to a point somewhat below level 6. The average ore contained 5 to 6 per cent of lead and 8 to 100 (or more) ounces of silver and $1 to $2 in gold to the ton. There was very little limonite and scarcely a trace of copper except near the bottom of the stope. In places the ore contained large plates of barite.

Near the shaft there are comparatively few ore bodies, but toward the south end line from a point about 300 feet south of the shaft the several channels, here trending N. 10° W. and connected by many east-northeasterly cross breaks, become very regular and pro-

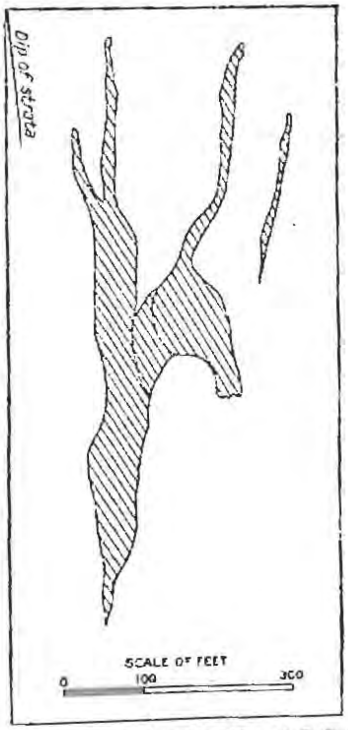


FIGURE 28.—Section between Eureka Hill and Bullion Beck shafts, showing Silver Gem and Eureka ore bodies joining. (After Tower and Smith.)

ductive on all levels above No. 9. These several bodies occupy a width from east to west of about 300 feet.

East of the New Year's channel a little lead ore has been mined in the Robbins tunnel near the surface. Otherwise the New Year's channel is the most easterly line of ore bodies, and almost continuous surface workings have been opened on it from the Eureka Hill shaft up to the Centennial Eureka line. In the lower levels down to level 6 this channel has proved productive, though not uniformly so. The stopes have about the same width as at the surface—that is, not more than 20 feet—and they may be continuous for several hundred feet.

On the Eureka Hill and Gem channels no ore has been found above level 3, but on levels 3, 4, and 5 a strong line of stopes begin on the Gem channel continued into Eureka Hill ground from the Caroline stopes of the Bullion Beck. The so-called Silver Gem stopes begin a little above level 4 and, extending N. 10° W., become very prominent on level 6, in which they extend in almost straight line for 800 feet to the Centennial line; they are 10 to 30 feet wide and near the south end line connect on two cross fractures with the Eureka Hill channel. These stopes do not reach level 7.

On levels 7 and 8 a series of stopes lying halfway between the New Year's and Gem channels become very prominent about 700 feet south of the shaft, and a cross break with copper ore near the south end line connects them with the Gem channel on level 6 (fig. 27). These stopes, which are in places 20 feet wide, contain mainly copper ores. In some of the stopes galena is associated with enargite and oxidized copper ore. Some stopes of copper ore change along the strike to lead ore; elsewhere lead ores and copper ores may be found side by side in the same stope. Both are primary ores and apparently were deposited at the same time.

The largest of these copper stopes is 150 by 30 feet in horizontal section. It contains ore carrying 2 per cent of copper and 10 to 20 ounces of silver and 0.25 ounce of gold to the ton. South of the boundary line all three "channels" continue into Centennial ground.

Type of mineralization.—The Eureka Hill mine has produced chiefly oxidized lead ores with some galena. It contains, however, especially in the southern part, toward the Centennial Eureka, minor shoots of copper ore, with which barite is associated. The principal mineralization found expression in silicification, but this did not extend far from the ore bodies; a few feet away from a body of lead ore one may find solid limestone, and a few feet north or south of the ore lens the fissure may be in massive limestone.

The principal ore is formed by replacement of the dolomite and limestone by quartz,

with a little barite and galena. This quartz is fine grained or cherty, and much of it is dark gray. Irregular cavities contain white quartz, and druses of minute quartz crystals may be seen in these cavities, but no coarse quartz.

In many of the copper shoots the mineralization spread away from the main body, but this was probably caused by the greater mobility of the copper salts. In the same shoots there is some limonite and black manganese ore, and in some of them also unoxidized enargite.

The conclusion can not be avoided that in this mine there are two kinds of primary ore. The predominant silver-bearing type consists of quartz, galena, pyrite, and zinc blende; the subordinate type carries quartz, barite, and enargite.

The ore.—The ore bodies are formed by the replacement of limestone or dolomite by gray or bluish jasperoid, containing barite, galena, and a little zinc blende and pyrite, more rarely enargite. The silicification extended in most places a short distance beyond the ore, but there are no large masses of jasperoid outside of the ore bodies. Numerous cavities looking as if caused by corrosion of the jasperoid are filled by white or gray quartz whose surfaces show small druses, and which is also associated with galena. The central parts of the large shoots are usually rich in silica and barite, but galena is more abundant along the margins, where copper ores may also occur. Gold and copper are found in the southern part of the workings.

There is not much zinc in the ore, and the residual galena from the deeper levels contains but little sphalerite. All the ore bodies are more or less completely oxidized, as the water level has not been reached in the shaft. Copper arsenates, cerargyrite, cerusite, and anglesite

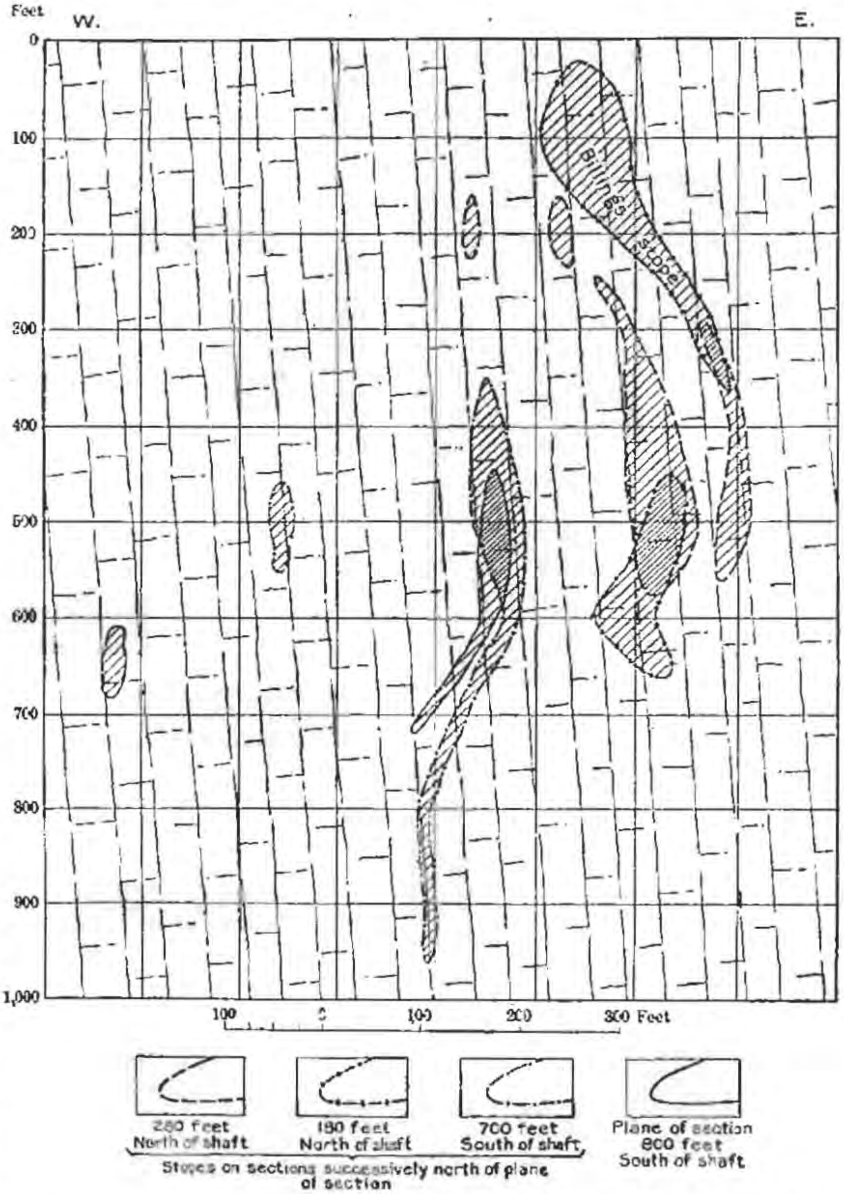


FIGURE 29.—Composite cross section of the Eureka Hill mine, showing form of ore bodies.

occur in abundance. Isolated occurrences of leadhillite, pyromorphite, and mimetite have been observed.

The lead ores are of basic or siliceous types, and their composition is illustrated by columns 1 and 2 in the following table, which also

gives in column 3 composition of a rich lot of oxidized copper ore:

Composition of ores of Eureka Hill mine.

	1	2	3
Gold...ounces per ton..	0.043	0.037	0.012
Silver..........do....	12.90	21.45	1.67
Lead........per cent..	20.70	5.15	....
Copper..........do....	.77	....	27.16
Iron............do....	17.50	2.80	7.30
Speiss(arsenides).do....	.50	....	....
Insoluble.......do....	29.70	75.20	18.60

1. At easterly cross breaks on 500-foot level.
2. Near station 70 on 500-foot level.
3. 1,000-foot level.

MINES OF CENTENNIAL EUREKA MINING CO.

Location and development.—The property of the Centennial Eureka Mining Co., controlled by the United States Smelting & Refining Co., comprises a number of consolidated claims aggregating 230 acres on the steep slopes of the ridge about a mile southwest of the town of Eureka. The shaft is about 600 feet above Eureka Creek, on the north slope of the ridge, The workings extend south underneath the narrow backbone of the ridge and connect in this direction with the Opex mine and in the deepest levels with the Grand Central mine. Toward the north the property is bordered by the Eureka Hill ground, and connections with this mine are established in the levels of middle depth.

The altitudes of the shaft collars on the several properties already mentioned are as follows:

	Feet.
Gemini	6,467
Eureka Hill	6,476
Centennial Eureka	6,887
Opex	6,961
Grand Central	7,149

Level 10 in the Centennial Eureka corresponds approximately to level 7 in the Eureka Hill. Level 18 in the Centennial Eureka lies about 40 feet below level 22 in the Grand Central and the 2,000-foot level in the Opex.

The developments comprise at least 20 miles of drifts, raises, and shafts and extend mainly over a zone 400 to 800 feet wide for 2,400 feet south-southeast of the shaft and 400 feet north of it.

The deposit is opened by a vertical shaft having a total depth of 2,281 feet, penetrating to an altitude of 4,606 feet. Twenty levels are turned, No. 20 having an altitude of 4,671 feet and No. 18 an altitude of 4,869 feet. A tunnel 2,207 feet long from Eureka Gulch intersects the shaft at a depth of 525 feet, or at an altitude of 6,362 feet.

Production.—The mine was first opened in 1876 but has been more actively worked since 1886. It has been the most productive property in the district and is distinguished by large and continuous ore bodies rather than by high-grade ore. The principal metals produced are gold, silver, and copper, and the value of the total output is about evenly divided between the three metals. The production of lead is small, and there is no zinc yield. The total value of the production has not been made public, but the dividends paid by the present company up to April 1, 1914, amount to $4,050,000. The total production certainly exceeds $25,000,000. During the 10 years from 1905 to 1914 the annual ore production has averaged about 100,000 tons, but since 1913 it has declined to about 60,000 tons. The gross value of the ore was for a long time about $30 a ton, but this also has been reduced in the last two years.

Water.—The original water level stood 18 feet below level 18, or at an altitude of 4,851 feet, 2,036 feet below the collar. On level 20, which does not extend far from the shaft, a strong flow of water was met on a cross fracture, but this flow is believed to be fed from one of the northward-trending fractures. In 1911 the water was bulkheaded on level 20, and about 1,000 gallons a minute was raised to tunnel level. In 1914 pumping had been discontinued, and the water level stood 75 feet below level 18. The quality of the water is discussed on page 123. A considerable amount of dripping water is found on levels 10 and 11, high above the permanent water level.

Geology.—The geologic features of this mine are complicated. The workings are in general in limestone or dolomite striking N. 5°–10° W. and dipping 70°–80° E., as shown, for instance, 200 feet south of the shaft on level 10 or 800 feet south of the shaft on level 11.

From level 16 to level 18 south disturbances are noted in the dip. About 500 feet south of the shaft on level 18 the bedding becomes confused and is in places flat or horizontal; this was especially noted under the South Dakota

stope, which is the southernmost stope in the mine. Similar flat dips are found in corresponding deep levels in the Grand Central and Opex mines.

The formations in which the ore is contained are the Cole Canyon and Opex dolomites and the Ajax limestone, but in the time available it did not prove possible to distinguish these formations in the mine workings.

On the surface just south of the Centennial shaft there is a great northeasterly fault along which the southern block has been moved about 200 feet to the northeast. No evidence of this fault has been noted in the workings, the ore bodies apparently being entirely independent of it. It is therefore believed to be the oldest dislocation, which has entirely healed before the ore-bearing fractures were developed. In the northern part of the property there are four northerly fractures which the ore follows, the most westerly being the Gem channel, but these find practically no expression in the faulting of the strata, though one of them—the New Year's fracture—is clearly shown on the surface.

Two great easterly fractures are very prominent in the mine and have had an important influence on the occurrence of the ore; they are designated the first and second cross breaks. Both dip 68° S.; one may be identical with the fracture shown on the surface west of the shaft; the other is probably the cross fracture shown on the surface 800 feet southeast of the shaft. A third important fracture is the "east limit," a northerly fault. It is vertical between levels 5 and 10, but somewhere between levels 10 and 12 its course is interrupted by the second cross break, south of which it dips 67°–80° W. from level 10 to level 18, its lowest exposure. This fracture is probably identical with the one shown on the surface 900 feet east of the shaft, and the developments in the deep levels, is doubtless identical with the main "parting" of the Opex mine. It is certain that some post-mineral movements have taken place along the "east limit" and planes parallel to it since the ore was deposited. Probably there has also been some movement along the first and second cross breaks.

Porphyry.—Several intrusions of Swansea rhyolite porphyry are observed in the lower levels. None have been noted above level 12, and none have been cut on level 18. All are in the northern part of the mine. One well-defined dike 6 to 10 feet wide, trending northeast, is exposed at several places on levels 12 to 16 and is evidently connected with a similar body in the Opex mine. Another dike 57 feet wide is cut on level 16 farther southeast, in the crosscut connecting with the Grand Central mine, and also probably connects with a similar body in the Opex lower workings. A flat body of porphyry 12 feet thick has been exposed by four raises from the most southerly workings on level 18, and this may possibly connect with the dikes mentioned to form a cup-shaped mass underlying the deepest ore body.

Northern ore bodies.—The occurrence of the complex and enormous ore bodies of the Centennial Eureka mine is chiefly related to northerly and easterly fractures. Beginning from the north the ore bodies follow the northerly fractures, which are dominant in the Eureka Hill, Bullion Beck, and Gemini mines and which in many places, but not everywhere, follow the stratification planes.

There are five of these northerly fracture lines—beginning from the west, the Gem, the Eureka Hill, the New Year's, the Big Platform, and the Never Sweat and "east limit." The first three continue from Eureka Hill ground and lie within a space of 300 feet from east to west; the last two make their appearance east or southeast of the shaft.

The New Year's channel begins at the shaft and continues north with conspicuous surface outcrops and open workings down to the Eureka Hill shaft. (See p. 193.) The stopes are at the most 15 feet wide and show westward offsets toward the north. They continue down to level 10 or level 11.

The Eureka Hill channel lies about 100 feet farther west and contains a series of copper stopes as much as 30 feet wide on levels 8 to 10, connected in places by ore on cross breaks with the Gem channel, which is 150 feet to the west.

The Gem channel is continuous from the Gemini mine and forms a system of lenticular ore bodies that strike a trifle west of north and are productive to a point 300 feet south of the latitude of the shaft. A long crosscut to the Golden Ray and West Mammoth ground west on level 6 has apparently intersected the Gem fractures but found no ore. The Gem channel is a fracture zone that is in places 100 feet wide. The ore bodies, which carry both

copper and lead with silver and some gold, extended from level 6 to level 11, but stringers were followed down to level 12. The ore, therefore, extends a little deeper here than in the Eureka Hill mine.

California column.—The great ore shoots of the southern part of the mine (fig. 30) are due largely to easterly cross breaks. The northern-nost great shoot, which may be called the California column, as it contains the California tope, connects with the Gem stopes on level and then follows the first great easterly cross reak downward, though not on its dip of 68° ut pitching about 45° southeast to the Kanas stopes on level 14. From this point the ore eaves the first cross break, flattens, and runs more nearly southward on levels 16 and 17 through the North Dakota stopes, about vertically below the saddle in the ridge south of the shaft, where its eastward extension is limited by the northerly fracture called the "east limit." In the most southerly workings, in the South Dakota stopes, the ore reaches the second cross break and continues across it. The flattening in depth is caused by the local flat dips of the strata, best shown on level 18, and apparently also by flat intrusions of porphyry. On the whole this body forms a southwestward-pitching pipe having a greatest diameter of 125 feet; in depth, where the ore flattens, the width is somewhat less, reaching a minimum of 25 feet.

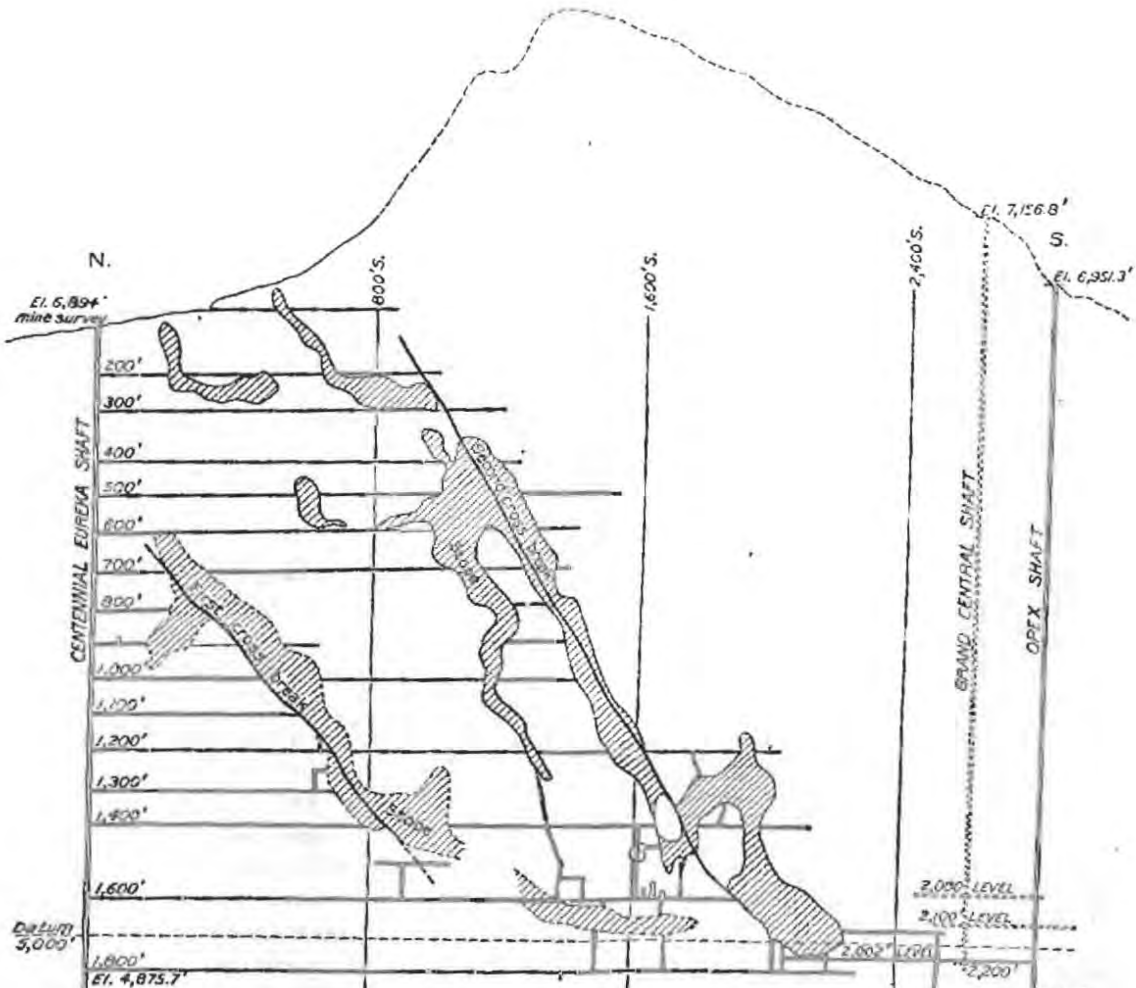


FIGURE 30.—Section showing approximate outlines of ore bodies south of the shaft in the Centennial Eureka mine.

The first cross break is a very regular fracture traceable from level 6 to level 14 with a dip

of 68°; the walls are smooth and in places slickensided; the striations are perpendicular to the strike. Along the cross break the footwall is locally solid limestone on which the ore rests directly, but elsewhere the ore may break through the wall.

In several places the east side of the ore is limited by a northerly fracture that belongs to a system of such minor breaks west of the "east limit," but in places the ore extends east of this fissure. Four raises from level 18, under the South Dakota stopes on level 17, have found clayey porphyry 40 to 60 feet above the level. Above the porphyry rests greatly disturbed limestone with large boulders, breccia, and open places. There is some reason to believe that the porphyry dike shown on levels 12 to 16 may connect by a flat body of intrusive rock under the South Dakota stope with the thicker dike shown on level 16 in the crosscut southeast toward the Grand Central boundary line.

Ore columns of the "east limit."—Just as the California column is related to the first cross break, so is the other great division of the ore bodies related to the second cross break; it is more specifically dependent upon the intersection of this second cross break with the northerly fracture called the "east limit." The pitch of the ore coincides roughly with the dip of the second cross break, which is 70° S.

In the same way as the northerly Gem channel leads into the California column, two northerly fractures southeast of the shaft lead into the second cross break.[1] Along one of these fractures are the so-called Big Platform ore bodies, which begin 300 feet east of the shaft on level 3 and continue, at first narrow, for several hundred feet until they widen to 70 or 80 feet in the Michigan and Montana stope; likewise between levels 2 and 3. On the south side of the Montana stopes the second cross break, dipping 70° S., is encountered and the narrow ore is continued on this plane eastward into the Oregon and Maine stopes, which are in places 100 feet wide.

About 600 feet east of the Big Platform line the Never Sweat channel begins in the relatively narrow Rhode Island and New Hampshire northerly stopes on levels 5 and 6. In the Maine stopes on level 5 the ore bodies begin to feel the influence of the second cross break and to go down on its southward dip.

From the Oregon and Maine stopes on levels 4 and 5 a column of stopes, gradually narrowing, descends steeply through the Pennsylvania stopes to the Missouri stopes on level 12 without following any of the fractures mentioned.

The strongest column, however, descends along the intersection of the second cross break and the "east limit," through the Utah, New Jersey, Minnesota, Virginia, and South Carolina stopes, the last on level 14, from which a connection is being established with the South Dakota flat stope on level 17. The South Dakota thus forms the converging point for two great ore columns of the mine. At the same time the ore begins to spread laterally, becomes more or less independent of the second cross break, and crosses east of the "east limit." This great pipe or column is at many places 100 feet in diameter; in some places its greatest extension is along the "east limit," in others along the second cross break.

In the South Carolina stopes several northward-trending walls were observed on which the ore was slickensided, showing some post-mineral movement.

Relation of ore to porphyry.—The dikes and irregular flat masses of Swansea rhyolite in the southern part of the mine from level 12 to level 17 are greatly altered by the introduction of calcite, sericite, and pyrite and contain a little silver and a trace of gold. On level 12 in the Virginia stope a dike 12 feet wide, trending N. 8° E. and having slickensided walls, goes right through the ore; at one place the ore is 14 feet thick on each side of the dike. The same relation is seen in the South Carolina stopes on levels 14 and 15 and many other places. It seems evident that the ore is later than the porphyry but that the action of the limestone on the ore-forming solutions was so intense as to prevent any ore being deposited in the porphyry.

Ore supply.—The production of the Centennial Eureka mine has decreased in the last few years with the apparent exhaustion of the great ore columns and the flattening of the ore in depth. It would certainly be risky, however, to say that the ore is exhausted, for although no ore was found on level 18 the mine offers possibilities of exploration

[1] The small Boarding House stope just south of the shaft on level 2 was supposed by Tower and Smith to be faulted 300 feet northeast to the Big Platform stope. This view is probably not correct; there is no evidence to support it.

along the several northerly fracture lines of the upper south levels and also below water level.

Though ore does not extend continuously to the deep west workings of the Grand Central mine, it seems probable that the ore solutions traveled from the fissures of that mine to the flat region at about level 17 in the Centennial Eureka and thence upward through the present ore columns into the New Year's and Gem channels. No ore has been found south of the South Dakota stope in the direction of the Opex property nor in the extensive and deep exploration in the Opex.

The ores.—The bulk of the Centennial Eureka ore contains copper, silver, and gold, and the primary ore minerals consist of barite, quartz, and enargite, with some pyrite and a little chalcopyrite. Galena occurs in places in the copper ores, and some shoots containing much galena with enargite have been found in the northern part of the property, toward the Eureka Hill ground.

The average ore has a gross value of about \$25 or \$30 a ton, but certain parts of the ore bodies are rich in silver and others are rich in gold. Native silver is reported to have been found on the upper levels—for instance, in the Great Platform stope between levels 2 and 3—and it is said to occur on the Eureka Hill channel, down to level 9. The main ore shoots appear to contain barite in quantities increasing with the depth, and in levels 14 to 17 in the Kansas and Dakota stopes it occurs in large masses of platy crystals. The jasperoid or silicified limestone does not extend far from the ore; in this respect the ore bodies differ from some of those in the lead mines. In many places, indeed, the unaltered limestone directly adjoins the ore, and here and there rounded masses of limestone are included in the oxidized ore. The copper is largely carried in the copper arsenates, but there are also minor quantities of azurite, malachite, native copper, and cuprite. The richest copper ore is said to begin below level 7.

Some enargite occurs in all the levels where copper ores are mined, but it is said that little was found above level 10. The scant amounts of galena in the copper ores were found mainly at the points or along the margins ("casings") of the stopes. No zinc blende was observed, though it probably occurs intergrown with galena in the lead ores. The fresh pyrite is poor; it is said to contain only 0.1 ounce of gold and 2 to 3 ounces of silver to the ton. The average ore contains about 68 to 70 per cent of "insoluble" matter—that is, quartz and barite.

The porphyry usually contains disseminated pyrite with much sericite and calcite, but this material is invariably poor, even that immediately adjoining rich ores. The officers of the mine state that it rarely contains over 0.5 ounce of silver and a trace of gold to the ton.

The ore in the Gem channel near the Eureka Hill line between levels 6 and 12 contained gold, silver, lead, and copper. The bodies are practically exhausted, and little could be seen of them in the old stopes. Tower and Smith say that lead and copper occurred in these ores in the ratio of 1:1. The ore was only partly oxidized but contained in places 100 ounces of silver and 1 ounce of gold to the ton. A specimen from level 11, 400 feet south of the Eureka Hill line, contained both enargite and chalcopyrite with their products of oxidation. The ore of the Gem channel contains more silver and lead but less gold and copper than the other ore in the mine. Some barite is present, and a rather wide zone of jasperoid surrounds the ore.

The ore in the New Year's channel, which crops out from the Centennial shaft nearly to the Eureka Hill shaft, shows a vein of jasperoid 15 to 20 feet wide in which are streaks and masses of limonite, malachite, and azurite, with a little galena and oxidized lead ores. This ore body contained mainly lead ores in Eureka Hill, but copper ores predominate up toward the Centennial mine. The New Year's channel did not carry ore in the lower levels, and none of these channels are productive beyond the great easterly cross break.

The Gem channel on the south leads into the first great ore column along the cross break, and here the lead ores sink into insignificance.

The ore in the California stopes between levels 9 and 10 is said to have averaged 3 per cent of copper, with \$8 to \$10 in gold and 15 ounces of silver to the ton. Similar ore is found in the other two southward-pitching ore columns, beginning from the Big Platform stope on level 3 and the Rhode Island stope on level 5. Some stopes—for instance, those on level 13—were unusually rich in copper, carrying about 10 per cent.

Some of the heavy sulphide ore in the South Dakota stope is unusually rich in lead, yielding 30 per cent, together with 15 per cent of copper, 10 per cent of iron, a varying amount of silver, and \$4 in gold to the ton.

Rich gold ores.—Although all the ore carries gold to the extent of \$4 to \$15 a ton, abnormally rich gold ore is found at many places—for instance, below level 16 in the Dakota stopes, on level 14 in the Kansas stopes, on level 9, in the Delaware stope, and on levels 2 and 3. It occurs, consequently, at all depths in the mine. This gold ore is fine grained, gray to rusty, and highly quartzose and was formed by the replacement of limestone. The gold appears to have been deposited by secondary processes. (See p. 176.) Some of this ore contains several ounces of gold to the ton, and one carload from the Delaware stope contained 16 ounces to the ton, returning \$16,000.

Rich silver ores.—In the same manner unusually rich silver ores are found at some places. In places these are due to a concentration of silver chloride, but in the deeper levels, where there is more enargite, the abnormal content in silver seems to stand in connection with the development of chalcocite and covellite, and rich secondary silver sulphide or sulpharsenides were probably formed. Such ore from the South Dakota stope yielded as much as 1,500 ounces of silver to the ton; a record carload from the Michigan stope in the Eureka Hill or New Year's channel on level 3 yielded \$33,380 net, mostly in silver.

Some of the high-grade copper-stained barite in the lowest part of the mine is rich in silver, containing about 80 ounces of silver and 0.5 ounce of gold to the ton.

DEVELOPMENT WEST AND SOUTH OF THE GEMINI ORE ZONE.

The West Cable shaft, according to Tower and Smith, is 500 feet deep and is at the mouth of Cole Canyon, west of Eureka.

The Herkimer shaft, 500 feet deep, is on the southwest slope of Eureka Peak, north of Mammoth. There is an outcrop of jasperoid, evidently along a northerly fracture, just north of the Herkimer shaft. The Southern Eureka shaft, just east of the Herkimer, is also 500 feet deep. The Annandale shaft, in the same vicinity, is 200 feet deep. The Tennessee Rebel shaft, on the lower slopes of Eureka Peak northwest of Mammoth, is 500 feet deep. Some crosscutting has been done from most of these shafts, but no ore bodies have been found. Fractures trending mainly north or N. 15°–30° E. are common, and silicification has been observed along some of them.

EMERALD PROPERTY.

The Emerald mine, owned by the Emerald Mining Co., is northwest of Mammoth, near the end of the south spur of Eureka Peak. No ore bodies of commercial importance have been found here save possibly an undeveloped deposit of soft red iron ore. A little isolated bunch of oxidized copper minerals has also been found.[1] The underground workings consist of a 1,000-foot shaft (altitude of collar 6,830 feet), a winze from the 1,000-foot to the 1,100-foot level, with accessible drifts and crosscuts on the 400, 500, 600, 700, 1,000, and 1,100 foot levels. A 1,900-foot level has been run from the 2,000-foot level of the Opex shaft.

The workings lie in Upper Cambrian and Ordovician strata (including the Opex dolomite and the Ajax limestone). The beds are slightly overturned at the surface, with a N. 10° E. strike and a 75° W. dip, and maintain this altitude as far down as the 500-foot level, below which they curve to a northwesterly strike and moderate to steep northeasterly dip.

Faulting is very pronounced. The Emerald-Grand Central fault crops out just east of the shaft house, crosses the shaft at the 100-foot level, and has been cut on the 400, 500, and 600 foot levels. Its underground course is undulating, the strike ranging from N. 20° E. to N. 45° E., and the dip from 50° to 70° NW. Its walls, where exposed, are highly slickensided, and its course is marked by much brecciation and a little mineralization. Its horizontal displacement can not be exactly determined but is over 300 feet; the southeast wall has moved relatively northeastward. A second northeasterly fault is exposed on the 400-foot level, where it dips 42° NW., but evidently it joins with the first before reaching the 500-foot level. At greater depth, west of the Emerald shaft, the Emerald-Grand Central fault may join the southern part of the main fault, or

[1] Three years after the writer's visit it was reported that 4 feet of lead-silver ore had been opened on the 700-foot level (Min. and Sci. Press, Oct. 31, 1914, p. 702), but no shipments of ore from this mine have been reported.

"parting," in the lower Opex workings. Easterly faults, mostly with southerly dips and with horizontal offsets of as much as 40 feet, are rather numerous, and a few of them carry a little vein matter. The amount of offset is proved by the positions of the Emerald dolomite member of the Ajax limestone. Northerly fissures are also numerous, and some are marked by intense brecciation and more or less vein matter, but the amount and direction of faulting along them have not been proved. The easterly faults fail to cross either the northeasterly or the northerly fissures.

The mineralization consisted for the most part in the formation of calcite veins and pockets accompanied by varying amounts of limonite and psilomelane or wad, but there also occurs a considerable amount of soft red hematite, some silicified limestone, and small amounts of copper and lead minerals, which in some assays have shown the presence of arsenic and antimony. The greatest development of calcite is on the 500-foot level, where a zone as much as 150 feet wide has been traced 300 feet northward from a point 250 feet west and 400 feet north from the main shaft. Where the calcite in this zone lines cavities it forms long, pointed crystals (scalenohedrons). This zone is said to have been cut on the 700-foot level, but the workings were not accessible at the time of visit.

The soft red iron ore lies in or close by the main northeasterly fault and has been found at several points on the 400 and 500 foot levels. On the 600-foot level also the northeasterly fault carries some iron ore, analyses of which show a little arsenic and a very little though constant amount of copper.

The only other noteworthy indications of mineralization are a small bunch of barite reported from the 700-foot level, a little "antimonial lead" reported from a winze on the 1,000-foot level, and some silicified rock at the east end of the 1,100-foot level, similar to that associated with the iron ore on the 400-foot level.

OPEX PROPERTY.

The Opex property, now controlled by the Opex Mines Co., one of the Knight properties, of Provo, Utah, is on the next spur west of the Emerald and extends from Mammoth Gulch northward to a point within 500 feet of the crest of the ridge. The old shaft was sunk near the south end of the spur, but the new shaft (altitude of collar 6,961 feet), from which extensive prospecting has been conducted, is about 1,500 feet farther north. The new shaft is 2,200 feet deep, and drifts have been run on the 1,300, 1,500, 1,700, 1,800, 1,850, 1,925, 2,000, and 2,147 foot levels. The bottom of the shaft has struck ground water, which stands at the 2,170-foot level.

The workings are mostly within the Opex dolomite, except the long west drift on the 2,000-foot level, which, when visited, was being driven to reach the quartzite and shale contact. The strata along this and other drifts west of the shaft as a whole dip uniformly about 80° W., proving that the west limb of the great syncline is slightly overturned to a depth of at least 2,600 feet below the crest of the ridge. There is considerable irregularity of dip around the shaft, due to minor flexures. South and east of the shaft the strata assume a southeast to nearly east strike, with northeast or north dip, presumably forming part of the same flexure that was found in the lower workings of the Emerald, possibly indicating the flattening of the beds toward the axis of the main syncline. A large cave lined with stalactites and stalagmites has been exposed on the 2,000-foot level, a little over 100 feet north-northeast of the shaft.

The lower levels in a north-south zone through the shaft have exposed a dike of rhyolite porphyry (see p. 49), faulted into two parts, which converge south of the shaft. The dike is tongued-shaped and has a steep easterly dip and a southward pitch. It is highly impregnated with pyrite, but the adjacent limestone is not mineralized, except for a few microscopic crystals of pyrite and quartz which could be interpreted as primary constituents of the rock. Another body of rhyolite porphyry of irregular but not fully known shape has been cut about 300 feet west of the shaft on the 2,000 and 2,147 foot levels.

The fault, which divides the dike, is known in the mine as the "parting." It has been followed from the shaft on the 2,147-foot level for about 1,560 feet slightly west of south and over 400 feet slightly east of north, with a dip of 60°-80° W. Its course for the last 100 feet northward swings to N. 30° E. Its footwall is mostly in hard dark bluish-gray dolomite and is highly slickensided; its hanging wall as a

rule is badly shattered. The same fault has also been cut on the 2,000, 1,925, 1,700, and 1,300 foot levels and maintains its tendency to swing northward and upward to a northeasterly course. Its southernmost exposure on the 2,147-foot level is about due west of the Emerald shaft and in line with the downward projection of the main fault in the Emerald workings; its northward portion is in line with the "east limit," a strong fissure of northward trend that forms the east boundary of the large ore bodies in the Centennial Eureka mine. The horizontal displacement, as shown by the dike, is as much as 350 or 400 feet, the eastern wall moving relatively northward. The upward displacement of the eastern wall may be 200 feet or more. The western part of the dike forms the hanging wall of the fault for about 400 feet on the 2,147-foot level; the eastern part forms the footwall for 75 feet where the fault is exposed on the 1,925-foot level.

Several easterly breaks are exposed in this mine, but the general uniformity of the rock prevents any accurate measurement of displacement along them. In one place the "parting" or main fault is offset for about 1 foot at its junction with two easterly breaks, that to the west of the "parting" dipping steeply north and that to the east dipping steeply south.

The only evidences of mineralization are scattered pockets of calcite crystals (scalenohedrons) more or less coated with black manganese stains along the "parting," and one bunch of barite, also along the "parting," at the south end of the 2,147-foot level. The extensive prospecting operations in the Opex mine were undertaken in the then reasonable hope of finding the extension of the ore bodies of the Centennial Eureka mine. Later developments have shown, however, that the ore bodies of the Centennial Eureka connect with those of the Grand Central mine instead of continuing due south.

GOLDEN RAY & WEST MAMMOTH PROPERTY.

The property of the Golden Ray & West Mammoth Mining Co. lies west of the Centennial Eureka. Its tunnel entrance is in a northwestward-sloping gulch, about 2,100 feet almost due west of the Centennial Eureka shaft. The workings cut all the Middle Cambrian shale and limestone strata from the Ophir formation on the west to the Cole Canyon dolomite on the east. These strata lie nearly vertical and are traversed by many northerly and easterly fissures. The workings include a south and a southeast drift on the tunnel level, with some crosscuts, a winze 300 feet deep in the southeast drift about 825 feet from the entrance, and a short drift on the 300-foot level.

The south drift lies wholly in the Ophir formation of argillaceous limestone and shale. It extends for about 900 feet, and at its end there are crosscuts extending for about 600 feet westward and 300 feet eastward. The drift follows for a considerable distance a slickensided fissure that strikes N. 10° W. and dips 80° E. to 90°. The slickensiding grooves pitch 45° S. The fissure is mostly tight, or filled with clay gouge ("talc"), but in a few places it carries lenses of white quartz and calcite as much as 3 inches in thickness, which are said to have assayed $8 to the ton in gold. In the east crosscut about 300 feet east of this fissure is a second fissure that strikes north and dips 80° E. This fissure is filled with brown and white calcite in columnar aggregates resembling onyx marble or travertine and terminating in long pointed crystals (scalenohedrons) around pockets. The immediate wall rock is badly shattered. At one place there is a vertical chimneylike cave 2 to 3 feet in diameter which extends upward along the fissure from the drift. The east crosscut has also exposed an easterly fissure dipping 80°–85° S., which carries the same kind of calcite. This fissure curves southward near the northerly fissure and joins it.

The southeast drift, or main tunnel, cuts diagonally across the strike of the rocks, exposing several open northerly to N. 10° W. fissures that dip parallel to the bedding. About 650 feet from the entrance it exposes the end of a small cave on a N. 85° W. fissure that dips 80° S. to 90°. The cave is lined with calcite scalenohedrons, and one bunch of ore about 10 inches in diameter is said to have been found on the hanging wall of the cave. The ore appeared to contain lead with some copper and probably some silver, but no assay of it was made. No prospecting has yet been attempted below this cave.

Around the 300-foot winze is a great irregular mass of white to brown calcite 20 feet or more in width, in shaly limestone. The body pitches about 70°–72° SE. It disappears from

the winze at a depth of 100 feet, and either the same mass or another in line with it is said to be cut on the 300-foot level 75 feet southeast of the winze and to spread southward and eastward along fissures in much broken rock. The calcite body was deposited in shattered rock at the intersection of northerly and easterly fissures, filling the fractures with comb-structure veins and replacing the rock fragments. Samples from the 300-foot level are said to have assayed 6 to 8 ounces of silver to the ton.

Near the end of the southeast drift, at the east boundary of the property, a south crosscut follows for a short distance a strong slickensided fissure and is approximately in line with the Gem channel on the 600-foot level of the Centennial Eureka mine that strikes N. 10° E. and dips 65° E. There are two systems of slickenside striations, one nearly horizontal and one pitching steeply northward. A broad zone 100 feet in maximum width and lying on both sides of the fissure is thoroughly shattered and filled with coarse brown to white calcite scalenohedrons and shows a considerable amount of iron and manganese staining. The zone passes northward, crossing the east boundary of the property at a very small angle. A grab sample from this zone is said to have yielded $1.92 in gold and 2½ ounces of silver to the ton.

DAGMAR PROPERTY.

The property of the Dagmar Northwest Mining Co. is on the east slope of Teutonic Ridge, west of Cole Canyon and north of Eureka Gulch. The workings include a 350-foot shaft (altitude of collar 6,806 feet) with drifts at the 200 and 350 foot levels; also two short tunnels about 600 feet northeast of the shaft.

The country rock is Middle Cambrian limestone and dolomite, which strike a little east of north and dip 60°-80° E. The ground is much faulted. The largest faults include one of northeast trend in the southern part of the property and one of northwest trend in the northern part. In the angle between these are several faults trending nearly due east.

Besides these faults there are three or more parallel fissures, or fissure zones, trending north to N. 20° W. and all showing some evidence of mineralization. The western fissure zone extends along the crest of the 7040-foot ridge and is marked by outcrops of iron-stained breccia, cemented in part by dolomite spar but mainly by scalenohedral calcite. The middle fissure extends along the west edge of the dump and is cut by the shaft at shallow depth. It also is iron stained and is characterized by small cavities lined with dolomite spar and by partly dolomitized walls. Grains of "steel" and "cube" galena and possibly of zinc blende are thinly scattered through both the dolomitized rock and the spar. In a winze on the 350-foot level, 80 feet southeast of the shaft and in the middle fissure zone, are exposed a few stringers of quartz accompanied by a little barite, dolomite, and a few specks of copper stain. The eastern fissure zone also contains small amounts of dolomite spar with a little galena. Loose sandy material from some of the leached fractures or stringers in this zone is said to have assayed 6 ounces of silver and a trace of gold to the ton.

North of the Dagmar property on the east slope of Jenny Lind Canyon, is a prospect in the Ophir formation, from which a little copper has been reported. In the canyon south-southwest of the Dagmar considerable work has been done in fractured ground, strongly stained with hydrous iron and manganese oxides and full of secondary calcite; but no fragments showing primary mineralization were seen on the dump. These two prospects may be further evidence of mineralization in the area west of Cole Canyon, but here as in the exposed parts of the Dagmar property the country rock is not the most favorable to replacement, and the mineralizing solutions that reached the level of the present surface were of the nonsiliceous type and evidently weak.

CHIEF MINE.

Situation.—The Chief Consolidated Mining Co. owns a large irregular area south of Eureka and controls the underground rights on the Eureka town site. The property borders on the south the Victoria and Eagle and Blue Bell claims and on the west the Gemini and Ridge and Valley claims. Its development is of recent date, practically all the underground work having been done since 1909, the date of its incorporation. The principal office is at Houghton, Mich. The company also owns some claims on Godiva Mountain, south of the May Day. In general the workings are in northward continuations of the ore zones worked in the Victoria and Eagle and Blue Bell mines.

The shaft is half a mile east-southeast of the Gemini shaft, south of and about 170 feet above the central part of the town of Eureka. The altitude of its collar is 6,570 feet. South of the shaft the slope becomes steeper and soon reaches the abrupt outcrops of the Eureka Peak ridge.

Developments.—The Chief vertical shaft is 1,815 feet deep and found ground water at that depth. It is sunk in talus and rhyolite to a depth of 300 feet. Levels are turned 500, 700, 800, 1,000, 1,200, 1,400, 1,600, 1,700, and 1,800 feet below the collar, and the workings are below the 800-foot level. They extend for 2,000 feet north-northeast and 1,300 feet south-southeast from the shaft. Crosscuts have been run east and southeast on several levels, particularly on the 1,400-foot level, which has explored the territory far east of the Victoria ore zone. The developments aggregate 22,000 feet of drifts and 4,400 feet of raises and winzes.

Production.—Up to June 30, 1914, 119,927 tons of ore from this mine had yielded 18,004 ounces of gold, 3,081,175 ounces of silver, 6,477,837 pounds of lead, and 119,927 pounds of copper, and the returns from the ore sales were $1,354,582. Dividends amounting to $262,838 had been paid.

Geology.—The surface of the Chief ground is occupied by the Packard rhyolite and the débris fans from the slopes of the Eureka Peak ridge. The shaft is sunk to a depth of 60 feet in débris from the slopes to the south, and then enters rhyolite, which extends to a depth of 300 feet. The rhyolite is more or less clayey and decomposed, contains finely distributed pyrite and chlorite, and yields a small quantity of sulphate water, unfit to drink. Scales of gypsum are seen in much of this altered rock. So far as known the pyrite carries no gold or silver. In the underlying limestone of the deep levels are several brecciated zones containing more or less rhyolitic material, especially 600 or 700 feet northeast of the shaft. On the 800-foot level contacts of rhyolite and limestone were observed. One place seemed to represent the bottom of the rhyolite flow, the contact dipping 30° E.; at another place only 100 feet distant the rhyolite appeared as a dike 20 feet wide, with much clayey limestone breccia along the walls. There is a possibility, then, that the flow is in places 800 feet thick. A dike of partly decomposed latite-andesite porphyry 10 feet wide cuts the Bluebell dolomite on the 1,600-foot level about 1,200 feet N. 55° E. of the Gemini shaft. Its average strike is about N. 70° E. Both the dike and the dolomite walls are slickensided.

A glance at the geologic map (Pl. I, in pocket) will show that the ore zones lie in the faulted blocks of the great Eureka Gulch dislocation, which have been thrown to the southwest by at least four step faults trending northeast. The workings of the mine must be partly in the Bluebell dolomite and partly in the Gardner dolomitic limestone, but it is extremely difficult to distinguish between these formations in the underground workings, and the thin intervening Victoria quartzite does not seem to be well developed in the Chief ground. It was not possible with the meager opportunities offered by the manager for underground examination in this mine to investigate the structure and trace the faults that divide the dislocated blocks. The ore zones apparently trend northward independently of the earlier faults, though the ore may in places be deflected to some extent along these cross courses.

The projection on the surface would carry the Victoria quartzite close to the Chief shaft, and the steep easterly dip would within a short distance carry the shaft well into the Bluebell dolomite. The strike of the heavy-bedded limestone is generally N. 10° W., rarely increasing to 20°, and the dip is steadily to the east at angles of 70° to 85°. On the 1,600-foot level, however, the beds, especially near the Gemini line, have prevailingly low and undulating dips.

Ore bodies.—The Chief shaft is sunk just west of a rectangular projection of Eagle and Blue Bell ground into the Chief property, and on some levels the drifts first extend north 400 feet and then east. A drift on the 1,000-foot level crossed this ground and intersected a fissure with some galena 400 feet southeast of the shaft; this is clearly the extension of one of the Blue Bell ore zones, probably the more westerly of the two.

Two principal systems of ore bodies are worked in the Chief mine. One centers about 700 feet northeast of the shaft and consists of two parallel bodies 100 or 150 feet apart. The second is separated from the first by about 1,200 feet of barren ground. It lies roughly

1,200 feet south-southeast of the shaft and is continuous with the deep ore bodies of the easterly ore zone of the Eagle and Blue Bell, with which connections have been made on the Blue Bell 1,350 and 1,550 foot levels.

The northern ore bodies were the first ones discovered and according to the reports of the company have been worked on the 1,300, 1,400, and 1,600 foot levels. The easternmost of these bodies carries principally lead ore, is as much as 40 feet wide, and pitches northward. It has been followed for at least 500 feet north from the Blue Bell line and toward its north end merges into lower-grade quartzose material. The easterly ore zone in this vicinity continues for 600 feet on one of the levels and is in places 30 feet wide.

The southern ore bodies, which connect with the Eagle and Blue Bell, extend horizontally for 500 feet and vertically from the 750-foot level to the 1,400-foot level. Their width and configuration can not be given. On the whole they are probably little different from those of the Gemini and Eureka Hill. The stopes excavated a succession of podlike masses of ore separated by lean, silicified limestone. The pitch is distinctly but irregularly northward.

The ores.—The Chief mine produces ores of several kinds. Among them are massive galena and lead carbonate ores containing say 0.05 ounce of gold and 30 to 40 ounces of silver to the ton, with 18 per cent of lead. Such ores were mined from the westerly ore zone of the northern bodies; in the easterly zone of the same locality rich siliceous ores carrying horn silver and ruby silver, were mined, one car of which netted $6,000. There are also in this vicinity large amounts of low-grade siliceous ore, carrying about 10 ounces of silver to the ton and a small percentage of lead. The reduction of such ore is difficult, and attempts have been made to perfect a cheap process for treating it. Much of it is cellular and honeycombed quartz with coatings of lead carbonate, lead oxychlorides, ferric sulphates, and small amounts of malachite, azurite, and conichalcite. The average composition of the ore mined from the northern ore bodies is perhaps best shown in the report of the company for 1911, when the average assay values were 0.048 ounce of gold, and 39.58 ounces of silver to the ton and 5.28 per cent of lead.

Though little is known of the character of the ores in the southern ore bodies, it is certain that they are more or less similar to those of the Eagle and Blue Bell mine. In part they are heavy lead ores, of mixed, sulphide and carbonate; in part they are highly siliceous ores, rich in gold and silver. To some extent this condition is reflected in the average assay values for 30,000 tons of ore mined in 1912, which yielded 0.2557 ounce of gold, and 29.83 ounces of silver to the ton and 1.36 per cent of lead.

The average gross value of the ore was $25.55 a ton in 1911, $24.15 in 1912, and $16.29 in 1913. The cost of smelting, freight, and sampling is about $9 a ton.

As elsewhere in the district, the primary ore is a dark siliceous replacement rock, in places banded and containing no residuary calcite or dolomite but scattered prisms of barite. This rock contains primary rather fine grained galena with a little zinc blende, enargite, and pyrite. Veins of a second generation of quartz cement the brecciated siliceous rock, which upon being attacked by oxidation becomes corroded and honeycombed, with the development of oxy-salts. Throughout the mine the ore is largely oxidized, but much galena remains, particularly along the "casings" of the ore bodies.

EAGLE AND BLUE BELL MINE.

Developments and production.—The property of the Eagle & Blue Bell Mining Co. is about half a mile southeast of the town of Eureka, in Eagle Canyon. The collar of the present working shaft has an altitude of 6,818 feet, or about 400 feet above the town. At the time of the earlier report (1897) this mine was developed only to a depth of 400 feet. During the last few years it has been opened to a depth of 2,019 feet (ground-water level), and it is now a large producer of heavy galena ore.

The principal developments consist of an old tunnel opening the southern part of the property; of No. 2 shaft, which is 1,000 feet south of the tunnel portal and 1,043 feet deep, with levels 100 feet apart; and of the present No. 1 working shaft, which is close to the tunnel portal and has workings extending mainly eastward on the 700, 1,000, 1,200, 1,350, 1,550, 1,700, and 1,876 foot levels. The total openings amount to many thousand feet.

The 1,350-foot level of the mine connects with the 1,000-foot level of the Chief Consolidated property.

The production from 1897 to 1916, inclusive, was 220,343 tons of ore, yielding 35,385 ounces of gold, 3,217,676 ounces of silver, 1,413,102 pounds of copper, 33,796,415 pounds of lead, and 22,856 pounds of zinc, and having a total value of $4,450,905. Up to November 2, 1916, dividends of $532,518 had been distributed. In earlier years the ores taken out were siliceous and lean in lead; of late large bodies of galena ore have been found in the lower levels. There is very little copper, the principal value of the ore being in lead and silver.

Geology.—The surface and the workings in the vicinity of the working shaft are in the Bluebell dolomite, which contains most of the ore. About 700 feet south of the working shaft, however, the drifts must enter into the striped Opohonga limestone, and much of this rock is in fact shown in the dump. Mr. Loughlin ascertained that the so-called "white lime," which at one place on the 1,000-foot level is faulted against the "blue lime," is really the Opohonga limestone in contact with the Bluebell dolomite. The boundary referred to corresponds to a fault along which the northerly block is thrown 500 feet to the west; this is one of the oldest dislocations in the broad faulted zone underneath Eureka Gulch. The shaft passes into the "white lime" at a depth of about 1,120 feet and continues in it to the 1,700-foot level, where a reversal of dip (65° W.) brings it again into the Bluebell dolomite, which persists with that dip to the 2,019-foot level. The direction and continuation of the ore channels are but little affected by the faulting, though the most northerly cross fractures appear to have had a local influence in guiding the solutions that deposited the ore.

Cross fractures trending east, east-northeast, and west-northwest are prominent; there are at least seven of them within 1,800 feet. One zone about 1,000 feet south of the shaft on the 900-foot level evidently corresponds to the great fault shown on the surface. These cross fractures have generally a steep southerly dip. In detail the structure is probably very complicated. The stratification extends almost due north to N. 15° W., and the beds dip 65°–70° E.

No igneous rocks have been found in the workings.

Ore bodies.—The ore bodies are mainly determined by the intersection of inconspicuous, nearly vertical northerly fissures with certain strata that were susceptible of replacement, but they also in part follow northeasterly cross fractures. The trace of the northerly fissures is marked by more or less silicification of the dolomite.

There are two ore zones. The older developments on the west vein comprise the tunnel workings and several openings in ore below the tunnel level near No. 2 shaft, on the south side of the property. The newer and deeper developments lie northeast of No. 1 shaft, in the northern part of the property, and are separated from older workings by 800 feet of barren ground. The northern ore zone appears to lie about 150 feet farther east than the southern zone and is thus a little higher in the stratigraphic sequence.

In the tunnel a pipelike shoot was followed from a point near the surface to a depth of 400 feet. It is vertical for 300 feet, then pitches south at an angle of 60°, evidently following a cross fracture, and finally resumes its vertical position. Other ore bodies were mined south of the old shaft and on the south extension of the Beecher claim, on the 100 and 200 foot levels. From the 300-foot to the 1,000-foot level in the old shaft few ore bodies were found. The later developments on the 1,000 and 1,100 foot levels lie northeast of this shaft, just north of a cross break on which strong easterly faulting has taken place. This shoot is as much as 20 feet wide and follows the bedding planes of the Bluebell dolomite for 400 feet more or less continuously. It is of rather low grade but contains both copper and lead.

The richer ore bodies lie a few hundred feet northeast of No. 1 shaft on levels extending from 700 to 1,876 feet (1916). The most extensive developments are on the 914-foot level (equal to the 1,000-foot level in the old shaft). The occurrence of the ore is in general related to the intersection of an easterly cross break with the northerly fissure. The ore began 200 feet above the 914-foot level, and in 1911 the workings had disclosed it on the 1,100-foot level. It is in part siliceous and carries gold and silver with a little lead and copper; in part it is heavy lead ore, and both kinds occur sep-

arately but in close proximity. A body of siliceous ore rich in gold was found 100 feet south of the main ore body; in one place 68 feet below the 1,200-foot level the stope was 100 feet long and 125 feet wide from east to west, at the time of visit, when the whole extent of the body had not been developed.

In 1914 the mine was opened from No. 1 shaft down to the 1,550-foot level, and the mixed siliceous and lead shoot was found to continue to the lowest workings; in addition a new and very valuable lead shoot was found farther west, almost due north of the shaft.

The shoot of mixed siliceous and lead ore has been followed north for 480 feet and from the 700-foot down to the 1,500-foot level. It is 20 to 70 feet wide, and its general trend is north-northwest. In its lower part heavy lead ore predominates.

The new lead shoot lies 300 feet north-northeast of No. 1 shaft. Its top is at about the 1,450-foot level and its deepest part, so far as shown at present, on the 1,550-foot level; here it is 140 feet long and as much as 20 feet wide, a magnificent body of lead ore about half oxidized and averaging as a whole 20 or 25 per cent of lead. This shoot would appear to lie in the continuation of the West vein of the old workings to the south. The dolomite walls of the shoots are everywhere sharply defined.

During 1915 and 1916 new stopes were opened in continuations of ore shoots on the 700, 1,000, and 1,550 foot levels and on the 1,200-foot level of the Victoria mine. New stopes were also opened on the 1,700 and 1,876 foot levels east of the shaft. The relations of these two stopes suggest that the ore shoot follows the local westward dip of the inclosing rock. The newly exposed ore on the 1,876-foot level consists of coarse to fine grained galena partly oxidized to anglesite and cerusite and thinly coated in a few spots with an undetermined yellow powdery mineral. The shaft passes into low-grade ore, said to be of normal character, 50 feet below the 1,876-foot level but is in barren rock at ground-water level.

The ores.—The mine has produced ores of widely differing character but all carrying more or less lead, gold, and silver. Some copper was found in the southern workings, and in 1913 a pipe of rich enargite ore was encountered in the northern siliceous shoot in the 1,300-foot level. It was about 34 by 20 feet in diameter and 75 feet in vertical dimension. Zinc to the amount of 2 to 3 per cent was found in some of the lead ores from the upper levels. Bodies of oxidized zinc ores below the lead ore should be expected underneath the lead stopes, but none have yet been found.

The siliceous ores consist mostly of white, greatly honeycombed and cellular quartz of fine grain, in places "chalcedonic" and showing delicate agate-like banding; many such bodies are adjoined by bluish siliceous and compact rock, evidently silicified dolomite, which borders the unaltered dolomite with sharp contact. The large siliceous stopes may have averaged 0.5 ounce of gold and 20 ounces of silver to the ton, with 1 to 3 per cent of lead. The second-class ore left in the mine might contain \$3 in gold and 5 ounces or more of silver to the ton. Some of the richest siliceous gold ore contained 4 ounces of gold and 130 ounces of silver to the ton, 78 per cent of silica, 5 per cent of iron, and 2 per cent of lead in a gangue of corroded quartz and barite.

The lead ores of the lower levels consist mainly of carbonate with bunches of galena; carload shipments would average 20 per cent of lead and 23 ounces of silver to the ton. One heavy carload of 87 tons contained 74.8 per cent of lead, 2.6 per cent of insoluble matter, 11.6 per cent of sulphur, 0.4 per cent of iron, and 0.017 ounce of gold, and about 80 ounces of silver to the ton.

In 1913 a carload of heavy lead ore was shipped from the new shoot north of the shaft. The weight of this shipment was approximately 80 tons, and it consisted apparently of an almost pure mass of galena, anglesite, and cerusite. The shipment contained 74.8 per cent of lead (pure galena contains 86.6 per cent and pure carbonate 77.5 per cent). The ore carried 24.7 ounces of silver and 0.017 ounce of gold to the ton. There was only 2.6 per cent of insoluble matter in the ore; sulphur amounted to 11.6 per cent and iron to 0.4 per cent.

The ore carries a little barite but no calcite except as a late product of oxidation. Dark cherty silica with flakes of gold such as was

seen in the Victoria mine was not observed in this property.

Some of the ores have evidently had a long and complicated history of oxidation, which is not easy to work out in detail. In some of the siliceous ores a considerable concentration of gold and silver has taken place, but it is not probable that much lead has been dissolved and carried away from them. Chloride of silver occurs in places—for instance, on the 1,200-foot level—but no silver antimonides or native silver has been seen.

VICTORIA MINE.

Developments.—The Victoria mine, owned by the Victoria Mining Co. until 1915, when it was purchased by the Eagle & Blue Bell Mining Co., is on the northern slopes of Eureka Peak, in Eagle Canyon, about three-quarters of a mile south-southeast of the town of Eureka. It lies south-southeast of the Eagle and Blue Bell mine, and the Grand Central property adjoins it on the south, the Grand Central shaft being three-quarters of a mile south of the Victoria shaft. The altitude of the collar of the Victoria shaft is 6,998 feet, or about 600 feet above the town. The mine was not opened when the earlier examination of the district was made.

The shaft is 1,200 feet deep, and dry. The workings extend 400 feet north and 1,100 feet south of the shaft, continuing northward into Eagle and Blue Bell ground and southward into Grand Central ground, the general trend being S. 20° E. Drifts have been turned on the 900, 1,050, and 1,200 foot levels; the 600, 700, 800, and 850 foot levels are reached by raises from the 900-foot level. The 1,050 and 1,200 foot levels connect with the Eagle and Blue Bell workings. The 600, 700, and 900 foot levels connect with the Grand Central workings, the 900-foot level of the Victoria corresponding to the 1,100-foot level of the Grand Central.

The production of the property has not been made public but probably amounts to about $1,000,000; the order as to value of metal content is silver, gold, lead, copper. Shipments of ore have averaged about 3 carloads a week. Much second-class ore remains in the mine awaiting better conditions for reduction.

Geology.—All the workings are in the Bluebell dolomite, which in the northern two-thirds of the property strikes N. 30°–35° W. and dips mostly 50°–65° NE.; at a few places the dip is steeper. In the southern third the strike curves to almost due north. The thin Victoria quartzite lies a short distance to the east, and beyond it extends the Gardner dolomite, but the eastern dip of these beds carries them beyond the easternmost workings of the mine.

Several easterly faults or cross breaks have been observed, and on these the northern blocks, so far as known, are consistently thrown west, but the amount of displacement is not great; these faults represent the dying end of the great dislocations underneath Eureka Gulch. One such fault has been approximately located south of the shaft on the surface, and several are to be seen in the mine, but it is difficult without detailed examination to connect them with those on the surface. One of them, extending N. 72° E. from the vein and dipping 70°–80° S., is prominent on the 900 and 1,200 foot levels southeast of the shaft. Directly opposite, on the west side of the vein, is another, which is exposed on the 900-foot level and which strikes N. 72° W. and dips steeply to the south, approximately in line with the fault shown on the map about 400 feet southwest of the shaft. There are also many dislocations trending N. 25°–60° E. and dipping from 80° NW. to 45° SE.

Ore deposits.—No outcrops of ore are seen on the surface along the strike of the vein. In general the ore bodies trend N. 20° W., and the distance from the shaft to the most northerly stope, at the Eagle and Blue Bell boundary, is 500 feet. The stopes at the shaft are below the 900-foot level, which corresponds to the 1,100-foot level of the Grand Central mine, and are mostly on the 1,200-foot level.

In a general way the ore pitches to the north, but in strike and dip it follows the stratification planes, with local enlargements and offshoots along the cross breaks. The most southerly and highest stopes on the 600 and 700 foot levels follow two parallel shoots about 100 feet apart which are the direct continuations of the ore bodies of the Grand Central mine. The two shoots are joined at one place along a cross break striking N. 50° E.

The second group of stopes are 300 feet farther north, on the 700-foot level, and are bounded on the south by the N. 72° E. cross break. Here ore has been stoped continuously for 400 feet, and in this distance it curves

from a northerly to a N. 25° E. trend and pitches northward, the north end of the stope lying on the 850-foot level. The width of the stope is 60 feet in the widest part.

A small shoot lies 150 feet farther north on the 900-foot level along a series of northeasterly cross breaks that converge toward the southwest. About 100 feet to the northeast, on the 1,050-foot level, ore of the same type has been found, and this shoot has also been opened on the 1,200-foot level. The ore from the south boundary to and including this shoot contains prominent shoots of enargite, but a few small shoots of galena have been found in the upper margins of some of the stopes.

Between this shoot and the shaft, about 200 feet southeast of the shaft, a valuable though small gold shoot was found on the 1,100-foot level; it was 30 feet high and 6 "sets" (24 feet) square in cross section. It was an almost spherical mass of dark siliceous rock replacing limestone. The ore averaged 2 ounces of gold and 2 to 3 ounces of silver to the ton but contained no lead or copper.

East of the shaft great bodies of siliceous ore were opened in 1912 and 1913, principally on the 1,200-foot level, where the shoot extends, branching toward the northwest, for 180 feet to the boundary of the property. It evidently follows in part the stratification and in part the northeast and northwest cross breaks.

As opened on the 1,200-foot level the first long body of siliceous ore is as much as 24 feet wide and extends 30 feet above the level. At the north end of the workings the ore is 30 feet wide and wholly siliceous, no galena or enargite showing at the time of visit, in 1914. Since then this large body of siliceous ore has been found to continue for a considerable distance below and north of this level, in Eagle and Blue Bell ground. The contact of quartz and hard fine-grained limestone, which rarely shows stratification, is irregular but everywhere sharply defined. At one point on the 1,200-foot level was noted the unusual occurrence of a northeast fracture cutting across the quartz and thus distinctly later.

The ore.—The Victoria mine yields in general a highly siliceous gold-silver ore with bunches of copper ore and more rarely lead ore. The principal type, as shown in the deeper workings to the north, is a fine-grained, almost cherty quartz, in places with delicate agate-like banding. Extensive corrosion has produced irregular cavities in it, which are now filled with white, coarser quartz, much of it drusy and clearly crystallized in open spaces. Bunches of coarse-grained enargite are found in places, surrounded by an intergrowth of enargite prisms and quartz. A little galena occurs along the margins of the ore bodies and in sharp contact with unaltered limestone. Limonite and manganese dioxide are widely distributed in the ore but nowhere in large quantities.

The principal value of the ore is in gold, though much of the ore is of low grade and is for the present left in the mine; such ore runs from $7 to $10 to the ton. Much of the shipped ore contains 0.5 to 5 ounces of gold and as much as 120 ounces of silver to the ton.

Some shipments averaged 1.5 ounces of gold and 20 ounces of silver to the ton and 4 per cent of copper but no lead. Others have had a similar gold content but only 2 to 3 ounces of silver to the ton. Bunches of galena ore have yielded 20 per cent of lead and 0.20 ounce of gold and 23 ounces of silver to the ton but no copper.

Some of the galena ore on the 900-foot level contains much coarse spar of the ankerite type, but it occurs on separate fissures or on top of the white quartz of the second period rather than actually intergrown with galena.

Barite is present in most of the ore, though not in large amounts; it is associated with enargite. All the ore bodies are partly oxidized, but much galena and enargite remains. Very little pyrite is seen, and that mostly in altered limestone rather than in ore. Probably some pyrite occurred in the ore but has been thoroughly oxidized. The gold and silver are irregularly distributed; the silver is concentrated in places as silver chloride, and the gold, at least in the richer ores, is largely secondary and forms little bright-yellow scales adhering to the surface of joints in the dark quartz, without being accompanied by limonite, manganese, or other gangue. (See p. 177.)

GRAND CENTRAL MINE.

Developments and production.—The Grand Central mine is on the steep southeast slopes of Eureka Peak. The altitude of the collar is 7,149 feet. It is owned by capitalists of

Provo, Utah, who are working it under the name of the Grand Central Mining Co. The several consolidated claims extend between the Mammoth on the south, Victoria on the north, and Centennial Eureka on the northwest, and connections with these properties are made on several levels.

The mine is opened by the Grand Central shaft, which in 1914 reached a depth of 2,300 feet. A winze extends down 80 feet from the bottom level, the water level having been met in the bottom. Levels are turned at 100-foot intervals. The workings, which aggregate many miles in length, consist of crosscuts and drifts on an eastern vein zone which extends due north from the Mammoth to the Victoria, and of deep workings toward the west side which connect with the Centennial Eureka. Level 8 of the Mammoth corresponds to level 7 of the Grand Central. The Victoria shaft is 151 feet and the Centennial Eureka shaft 262 feet lower than the Grand Central.

The total production is not made public, but as the mine has been worked continuously and with reasonable efficiency the total output may be estimated at about five times the dividends. Up to September 15, 1914, dividends of $1,602,750 had been paid. In 1914 only about 2,000 tons of ore was shipped. The ores carry mainly silver, gold, and copper, with some lead.

At the time of the earlier report on the district the shaft was only 850 feet deep.

Geology.—The vertical shaft is sunk in Opohonga shaly limestone and remains in this formation to a depth of about 1,900 feet ("1,800" level), where it enters the underlying Ajax limestone. The principal zone of north-south workings is in the Bluebell dolomite, but some ore bodies along the West or No. 4 fissure are in the Opohonga limestone, and the lowest workings on levels 20 to 22 are in the Ajax limestone. At a distance of 750 feet N. 15° E. of the shaft on level 7 the contact of Bluebell dolomite and Opohonga limestone was cut, and this indicates a normal easterly dip of about 75°.

The normal strike is N. 10°–20° W. and the normal dip 70°–80° E., but both strike and dip are in places difficult to determine on account of the abundance of fractures. There are also many local irregularities. Dips of 45° SW. are found in some of the upper levels. On level 7 in the crosscut from the shaft the strike is N. 70° E. and the dip steep toward the north. On the same level near the Butterfly stope the beds strike N. 10° W. and dip steeply toward the west. On level 20 dips of 30°–50° NNE. were observed, corresponding to a similar position of the strata in the deep levels of the Opex and Centennial Eureka mines, farther west.

The principal ore zone follows prominent northerly fractures, which at the Butterfly stope are intersected by an almost vertical fracture trending N. 30° E. The West or No. 4 fissure also strikes N. 30° E., and west of the shaft the Emerald-Grand Central fault zone is intersected on the deepest levels, where it shows at least three fractures trending N. 30° E. and dipping very steeply west-northwest. Minor fractures trend northwest, N. 60° E., or east. The ore follows the N. 30° E. and northerly fractures. No igneous rocks were seen.

Ore bodies.—No outcrops of the ore bodies are visible on this property, and the highest workings are at level 4, near the Butterfly stope. The ore comes into the property in the Silveropolis shoot, adjoining the Mammoth at the southern boundary. This shoot begins near the surface in Mammoth ground and forms a pipe pitching 70° NW., across the stratification, probably following the intersection of two fracture planes. The dimensions, though irregular, are about 20 by 20 feet to 60 by 40 feet in horizontal cross section. This shoot crosses into Grand Central ground and continues, flattening somewhat, to levels 8 and 9. There it turns north, follows a steep fissure with the same direction, and continues due north approximately on the same level for 2,600 feet to the boundary of the Victoria mine. At first this shoot forms a series of irregular bodies confined between levels 7 and 8, then widening in the Butterfly stope to 50 or 70 feet and extending from level 4 to level 11. The Butterfly stope lies at the intersection of a northerly and a north-northeasterly fissure, both of which are nearly vertical. North of the Butterfly stope the shoot continues in a horizontal direction to the boundary line of the property and lies mainly between levels 7 and 10. A few hundred feet north of the Grand Central north boundary the ore turns north-northwestward into a new series of bodies in the Victoria mine. Figure 31 shows a generalized longitudinal section along this eastern and upper ore shoot

from the Mammoth on the south to the Victoria mine on the north.

Near the bottom of the Butterfly stope on levels 9 and 10 a new fracture, called the West fissure, was encountered. This fracture strikes northeast or north-northeast and dips 73° NW. Several minor ore bodies have been found along this fissure, beginning at the lower end of the Butterfly stope and continuing down to level 17. On level 18 a drift was extended south-southwest along this fissure and encountered new ore bodies apparently not connected with the more northerly shoot just referred to. These continued down to levels 20 and 21, following the flattening dip of the fissure. This ore apparently trends northwestward and lies in the extension of the horizontal projection of the Silveropolis column.

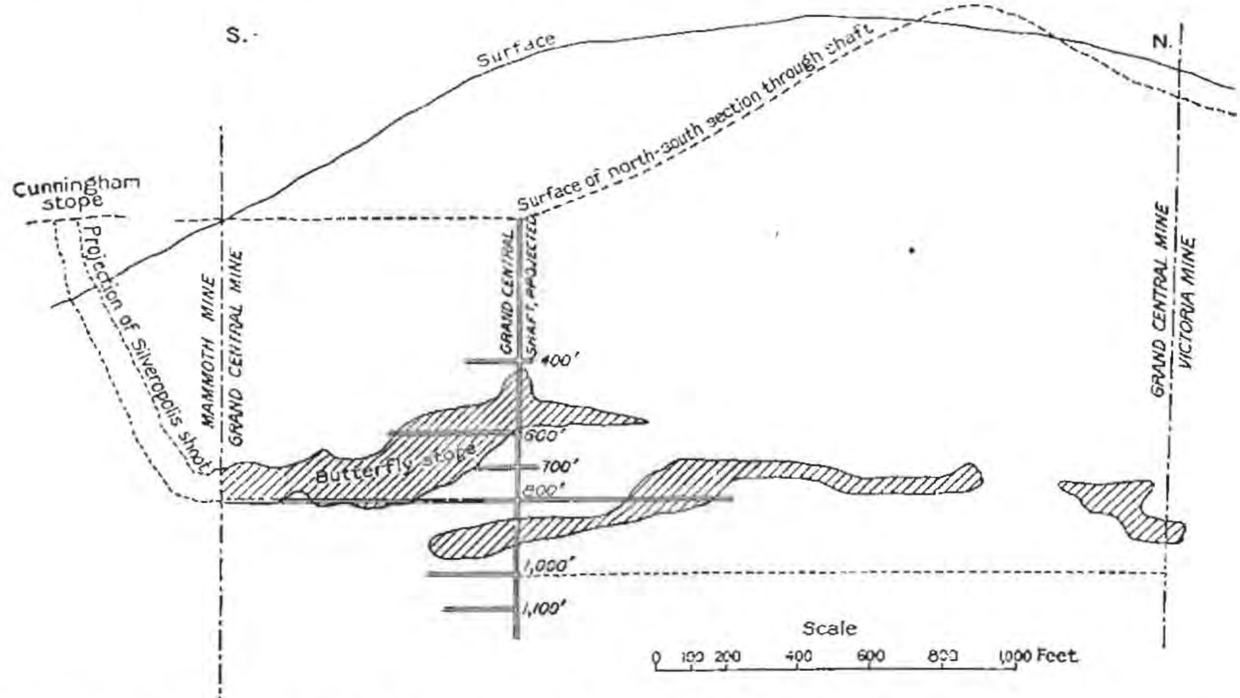


FIGURE 31.—Longitudinal section of the Grand Central mine, showing approximate outline of upper ore bodies from the Mammoth mine to the Victoria mine.

In the lowest levels the dip of the beds flattens to 40°–50° NNW. or NNE. Several smaller ore bodies are found here, in part following the stratification, in part occurring on a series of north-northeasterly fractures that are found at intervals in the same general northwesterly direction up to the Centennial Eureka line. Some of these fractures evidently form part of the Emerald-Grand Central fault zone which is so well marked on the surface. These smaller shoots were in general found between levels 20 and 22.

On the whole, then, the upper ore bodies in the eastern part of the mine follow northerly fractures but do not continue below level 11. From level 11 to level 17, in this part of the mine, the ore descended on a north-northwesterly fracture. In the western and deeper part of the mine the ore occurs mainly in shoots of horizontal trend along a series of north-northeasterly fractures. These shoots connect in a steplike manner, jumping from one fissure to another, and locally following stratification planes, so that the ore as a whole trends in a northwesterly direction. This ore practically continues to the boundary line of the Centennial Eureka mine.

The upper horizontal shoots between levels 7 and 9 were the richest in the mine. A large part of the siliceous ore mined now as second-class ore was left in the stopes during earlier work.

The ores.—On the whole the Grand Central ores contain copper, silver, and gold with a little lead; they are oxidized throughout, even in the deepest levels, and carry abundant arsenates. Toward the Victoria line, on the north, they are highly siliceous; in the deepest levels the ore

contains much barite and limonite and is in general similar to the ore of the Centennial Eureka.

Remains of sulphide ore are found at many places, however; they consist of enargite with a little pyrite, galena, and chalcopyrite. Chalcocite and covellite occur in small quantities throughout the mine, and the development of these secondary copper sulphides is usually attended by a concentration of silver. Horn silver is probably common but is rarely visible to the naked eye. Native silver was seen near the Butterfly stope. Vugs with small quartz crystals are common in the upper levels. Calcite in scalenohedral and flat rhombohedral forms was developed in the limestone and in the oxidized ore as one of the latest products. Silicified limestone usually surrounds the ore for a variable distance, but in the deep levels on the west coarse limestone is found in close proximity to some of the limonitic ore and locally forms boulders in the ore.

The ore mined is said to have averaged about $7 in gold and 12 ounces of silver to the ton; the tenor in copper is variable, but the average is probably less than 3 per cent. The lead is irregularly distributed, and much of it was found near the "casings" of the ore bodies. The siliceous ore now mined from the upper levels contains 1 to 2 per cent of copper. Much low-grade ore remains in the mine.

MAMMOTH MINE.

Location and development.—The Mammoth mine, a property of several consolidated claims, belongs to the Mammoth Mining Co. and has for many years been under the control of the McIntyre family. It is in the upper part of Mammoth Gulch, on the steep slopes leading up to Godiva Mountain, half a mile east of the town of Robinson.

The shaft (marked "Mammoth Hoist" on the map) is operated from a tunnel 211 feet below the collar, which has an altitude of 7,052 feet. The shaft is 2,100 feet deep, and a winze is sunk 260 feet below the bottom level, making a total vertical depth of 2,360 feet. The lowest level, therefore, lies at an altitude of 4,692 feet, or 100 feet lower than the bottom of the shaft of the Centennial Eureka. There is no water in the mine. The deeper levels are 100 feet apart, and the workings extend mainly north and northeast of the shaft to a greatest distance of 1,600 feet. The total length of the drifts amounts to at least 15 miles.

The ore bodies lie within 1,200 feet north and northeast of the shaft, on the Mammoth, Welding, Golden King, and Silveropolis claims.

Production.—The mine has been one of the most productive in the district and is still shipping ore. Mining operations began in 1872 and have been continued almost uninterruptedly since that date. The total production up to 1913 amounted to approximately 402,095 tons of ore containing $6,003,614 in gold, 6,942,314 ounces of silver, 17,184,124 pounds of copper, and 17,679,058 pounds of lead, valued in all at $14,660,197. The total dividends paid up to the end of 1916 amounted to $2,529,205.

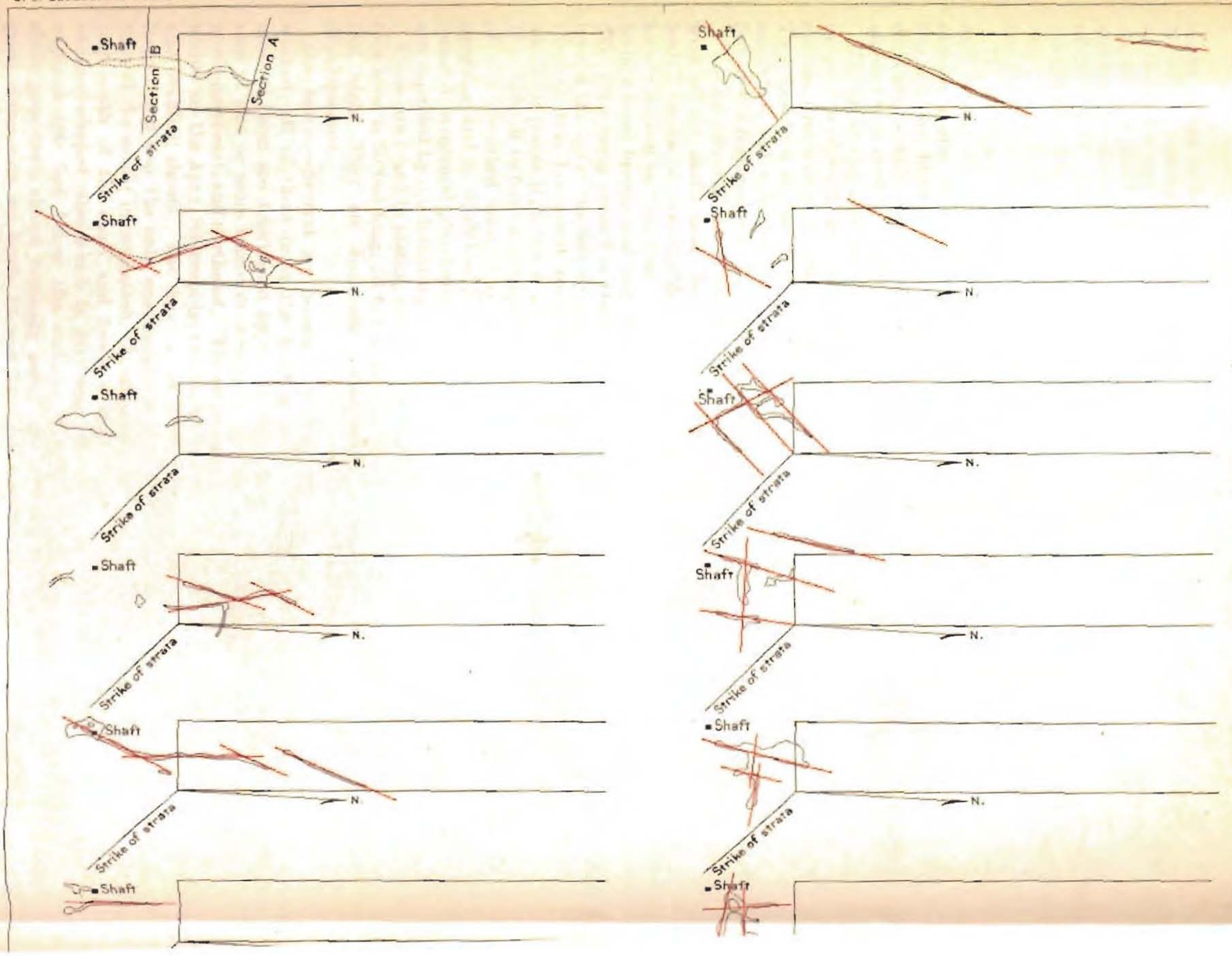
Recently much low-grade ore has been shipped from the large dump of former years, lessees have been working in various parts of the mine, and the underground operations by the company have been confined largely to the new copper shoot in the Welding claim. About 3,740 tons (748 cars) of ore was shipped to the smelter in 1914. From 1914 to 1916 the total annual shipments of ore averaged from 0.14 to 0.2 ounce of gold and 5 to 7 ounces of silver to the ton, 1.8 to 2.5 per cent of copper, and less than 1 per cent of lead.

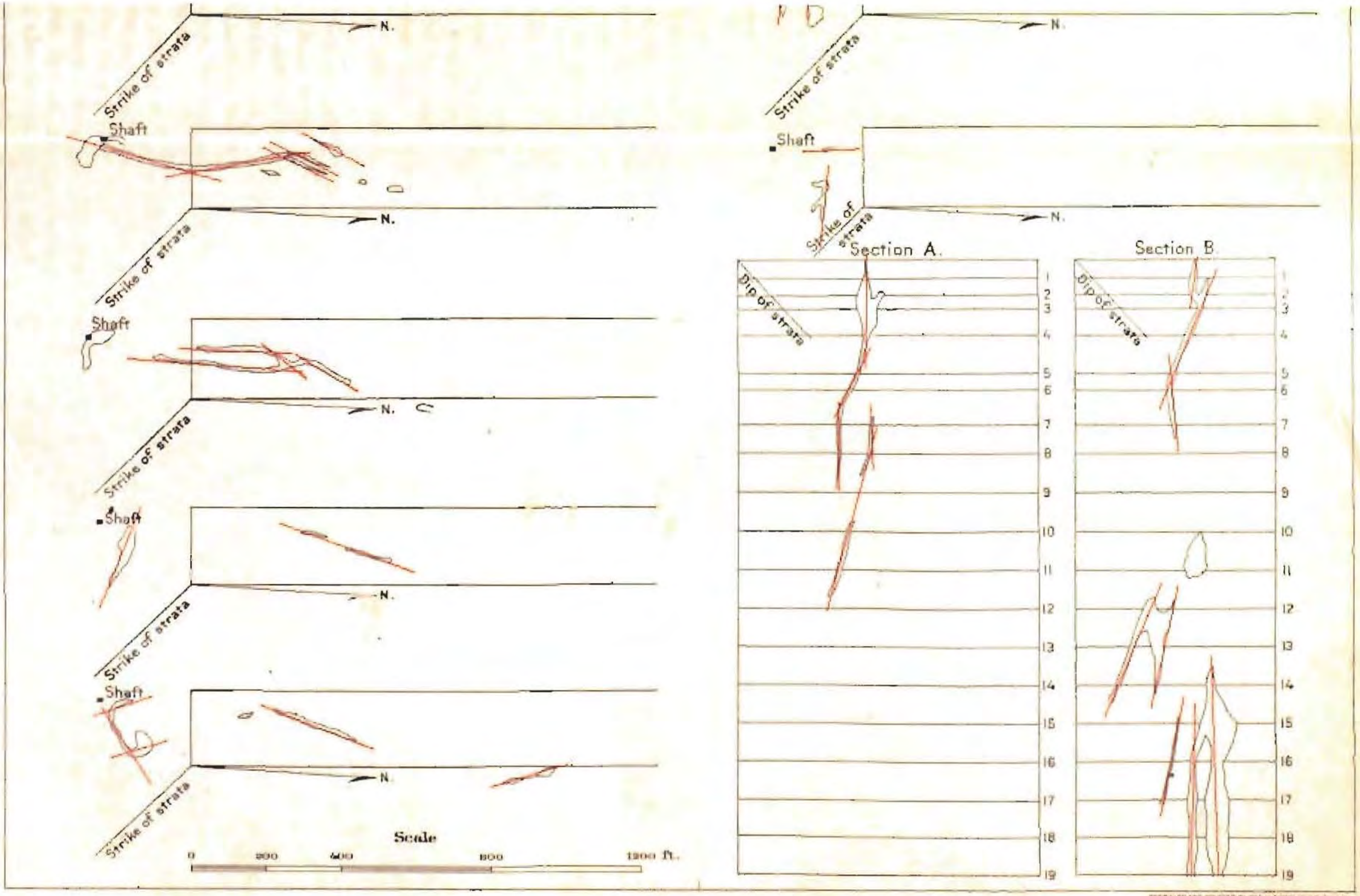
The ores contain chiefly copper, gold, silver, and lead. A characteristic of the mine is the marked segregation of ores into shoots of gold ore, lead ore, and copper ore, though of course the ore of each kind also contains other metals. Some of the ores were rich in gold, and the production probably averages not less than $15 in gold and 15 ounces of silver to the ton.

During the earlier years of the mine pan-amalgamation was the process used for the recovery of gold and silver, but even then some base ores were shipped to smelters. At the present time all the ores produced are smelted.

Geology.—The shaft is sunk in the Bluebell dolomite and almost all the workings are in this formation; some drifts, however, enter the Opohonga limestone on the west. No igneous bodies were observed on the surface or underground.

The strike of the beds is north-northwest, changing to more nearly north toward the Grand Central mine; the dips are mostly 65°–85° E., but in places they diminish to 35° or 40°. In some of the lower workings the


Shaft
Section B
Section A
N.
Strike of strata



PLAN OF ORE BODIES IN MAMMOTH MINE, BY LEVELS AND CROSS SECTIONS

strike swings more to the northwest or even N. 70° W., corresponding to the easterly bend of the strata east and southeast of the shaft. At the new ore body on the Welding claim, 800 feet north-northeast of the shaft, a strike of N. 70° W. and a dip of 40° NNE. were noted on level 8. On level 21, 800 feet northwest of the shaft, the strike is N. 60° W. and the dip 60° NNE.

The geologic map shows that the beds southeast of the shaft are disturbed by several easterly faults, the general result being that the northerly blocks are thrown to the west by dislocations whose horizontal component may amount to several hundred feet.

The fissures that control the ore bodies trend in part northward, but the most prominent system strikes from 10° to 35° east of north. Two members of this fault system, striking northeast, are indicated on the map. Very few of the fractures are of postmineral origin.

The limestone of the workings north-northwest of the shaft, near the Silveropolis ore body, shows a remarkable crushed zone, locally known as "the dike." The fragments form a loose breccia and may flow for several days after being opened in the workings. On level 4 the ore of the Silveropolis shoot passes through this brecciated zone or mud dike, which in places is as much as 100 feet wide. It is difficult to form a conception of the form of this disturbed zone; it seems to be very irregular and is doubtless a very late postmineral structural development. It is not accompanied by much faulting.

Caves are found in places; one on the 1,350-foot level is 50 feet long, 25 feet wide, and 30 feet high. They are distinctly postmineral developments.

Ore bodies.—Several ore bodies have been worked; all of them cross the bedding and most of them are determined by the intersection of two or more fractures striking north, north-northeast, and northeast. The principal bodies are the Apex, Silveropolis, Golden King, and Welding shoots. The Apex shoot is the largest and was the only one worked at the time of the earlier investigation. It crops out just south of the shaft and forms a large, chimney-shaped mass which in 1911 was well exposed 100 feet below the surface. This shoot goes down almost vertically and attains great dimensions on levels 15 and 16. The larger diameter trends N. 15° E., and it continues to level 21, where, however, it becomes of poorer grade.

The general pitch is 70° NE. but the outline varies greatly, as shown by Plate XXXIII, adapted from Tower and Smith's report. The shoot is evidently determined by the intersection of a system of fractures trending north, north-northeast, northeast, and east. The cross section is accordingly very irregular, and on some levels the shoot extends several hundred feet along northeasterly fractures. Its width is in places 100 feet. At the surface copper ores rich in gold were found; at middle depths of 1,500 feet a large lead shoot is recognized, adjoined by a gold shoot and, lower down, by a copper stope. On the lowest level the shoot is poor, though here, as elsewhere, silicified rock containing gold and silver extends on the north-northeasterly fissures far beyond the boundaries of the ore body. Some ore is also found on fissures extending eastward across the main direction of the body.

The next large ore body, called the Silveropolis shoot (fig. 32), begins near the surface 550 feet N. 109° E. from the shaft, and this also is located on a north-northeasterly fissure, which, however, dips 60°–80° NNW. and which on level 4 intersects the fissure of the Apex shoot. This upper body of mixed ores, now mined out, is called the Cunningham stope. It continues with a slight northerly pitch nearly to level 9, where it flattens out and is followed north-northeastward about horizontally on the corresponding levels of the Grand Central mine (fig. 31, p. 213). Drifts along fractures have been extended from a few hundred to 1,000 feet north-northeast of the Cunningham stope, but no ore bodies have been encountered.

The third ore body is found on the Golden King claim about 1,200 feet due north of the shaft; the stopes, which lie between levels 5 and 8, extend along a north-northwesterly fissure and lie close to the Grand Central boundary line.

The fourth group of ore bodies occurs entirely apart from the others, on the Welding claim. No ore crops out on the Welding claim, but a considerable body of oxidized copper ore was found on level 8 in the southern part of the claim; the ore trends N. 30° E. and has been followed for 300 feet. It evidently

occupies a fissure of the same system as those in the Opohonga and Gold Chain mines; the ore is about 80 feet long and as much as 30

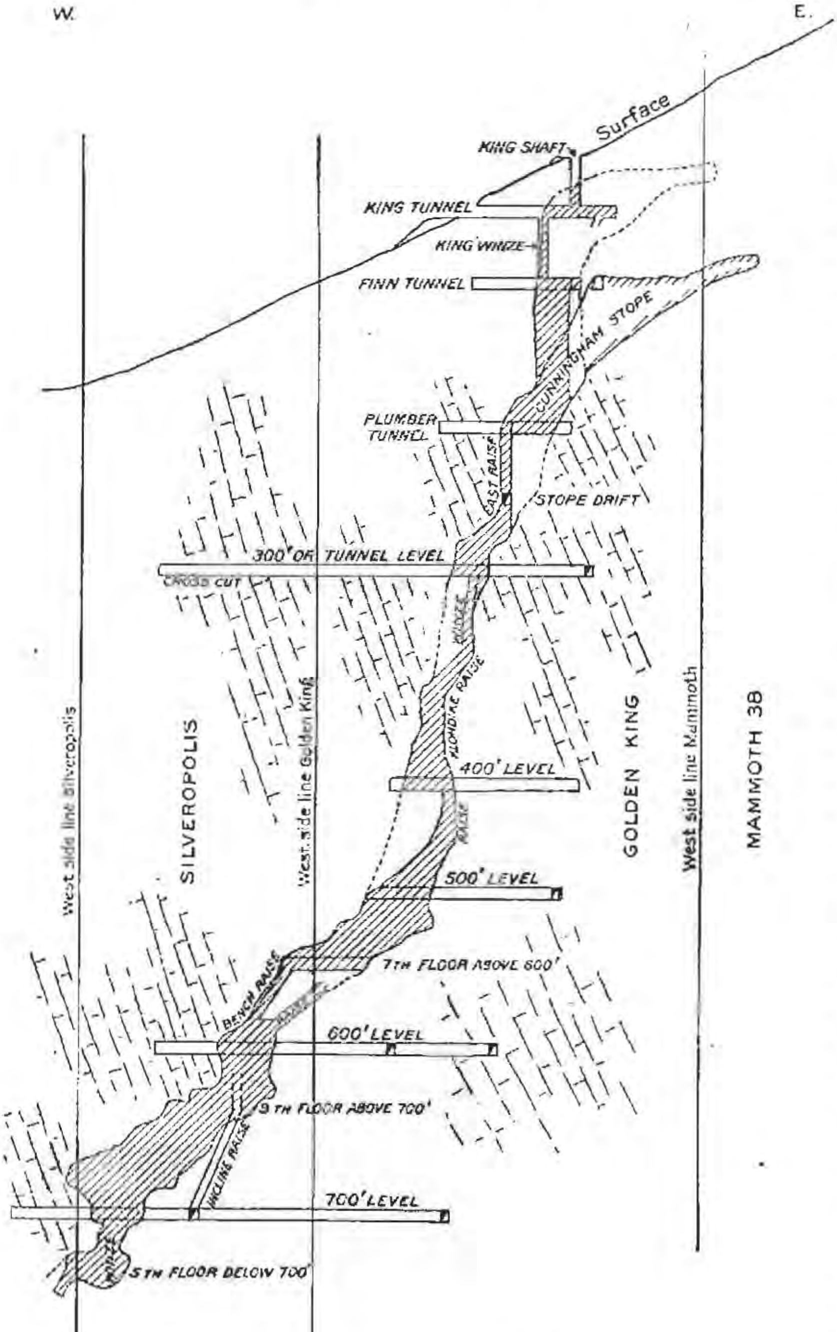


FIGURE 32.—Section showing Silveropolis shoot, Mammoth mine.

feet wide and has been stoped between levels 7 and 8. The ore is cut off by a fissure trending N. 60° W. and dipping 45° SSW., but this intersecting fissure is clearly premineral, for a few sets above the level the ore goes through it. The same fissure is apparent on levels 12, 17, 19, and 21. On level 19 a transverse body of gold ore follows this fissure. No ore is known to occur on this shoot above level 8 and but little below it. On level 22 some copper ore containing much gold in spots was found in a winze; this ore is said to follow the transverse fracture that cuts off the body on level 8.

The ores.—The ores of the Mammoth mine vary so much that a brief adequate description is difficult. In general the ore is siliceous and contains more or less limonite; the ore of shipping grade is surrounded by a wide zone of fine-grained silicified limestone, and much low-grade ore of this kind remains in the mine. The ore has a leached appearance and a cellular, corroded texture, so that in many places, on the lower as well as the upper levels, little remains except a honeycombed iron-stained material. Level 21, for instance, shows this texture in a particularly striking manner. The oxidation seems complete at this place, and the ore body looks exactly as in the most highly decomposed croppings, containing much limonite in cavernous and corroded quartz. Bunches of enargite and pyrite remain, however, in all the ore bodies at the surface of the Apex shoot, in the Welding shoot, and in the deepest levels.

The gangue, as usual, consists of extremely fine grained silicified limestone, brecciated and cemented by a coarser but still fine-grained

white quartz that in places forms small druses. Barite is fairly abundant.

All the ores contain gold, and some of them carry extremely rich spots where abundant fine-grained native gold is visible. The top of the Apex and the Silveropolis shoots were rich in gold, but the Welding shoot carries only $1 or $2 to the ton. Part of the Apex shoot on level 15 was so rich in gold that it was designated the "gold stope"; it immediately adjoined the big lead stope. The gold ores are all highly siliceous and associated with manganese dioxide; in the Silveropolis shoot there was much manganese down to level 6, and most of it was rich in gold. Barite containing native gold is reported from level 10. The poor and highly siliceous ore in the lowest levels of the Apex shoot contains gold as its principal valuable constituent, with little silver and no copper or lead.

Silver is present in all the ores. The Welding copper ore on level 8 is said to contain about 30 ounces of silver to the ton. The silver content of the Silveropolis shoot varies greatly, ranging from 10 to several hundred ounces to the ton. The great lead body of oxidized ore in the Apex shoot was rich in silver and also contained a little gold. Horn silver is, no doubt, the principal silver mineral; argentite may also be present, but it is rarely found in large amounts. Horn silver seems to have occurred mainly down to level 8 but is also found below that level. Some leaf or wire silver is also observed. On level 21, about 800 feet north of the shaft, toward the Grand Central ground, some very rich silver ore was struck in a flat "talc" seam. Some of this ore assayed several hundred ounces to the ton, and several carloads of this rich material was shipped. It contained very little gold.

Lead is present in small amounts as galena or cerusite in most of the ores, but the principal lead production of the mine came from a part of the great Apex shoot. This lead shoot was at its best close to the shaft on levels 13, 14, and 15, though it extended down to level 17. Its greatest cross section was 100 by 150 feet. Much of the ore contained 40 to 50 per cent of lead.

Copper is widely distributed and occurs mainly as arsenates, enargite, and famatinite. The oxidation is not complete, and plentiful masses of enargite remain. The arsenates are abundant, and fine specimens of clinoclasite, olivenite, and tyrolite are found throughout the ores. The gangue consists of fine-grained quartz and more or less abundant barite. The stopes in the Apex shoot were rich in copper from the surface down and extended vertically for many hundred feet. In the deeper levels a new copper ore body began just west of the shaft on level 16, but this body became poorer in the lowest levels; it contained mainly oxidized copper ores with little gold but 10 to 12 ounces of silver to the ton. The great Silveropolis shoot contained siliceous copper ore rich in gold and silver, the content ranging from 2 to 40 per cent in copper, $2 or $3 to several ounces to the ton in gold, and 10 to several hundred ounces to the ton in silver. During 1914 a stringer of rich bismuth ore, consisting mainly of bismuth arsenate in yellow, ochery masses, was found in the copper stopes of the Welding claim on the 600-foot level.

OPOHONGA MINE.

The Opohonga mine is opened on a small claim between the Black Jack and Gold Chain properties. At one time the workings were operated from the 300-foot level of the Black Jack, but lately the Gold Chain (Old Ajax) shaft has been used, from which levels 3, 7, and 10 open the Opohonga ground.

The country rock is the Opohonga limestone, which dips 30°-45° E. and is partly metamorphosed. The ore shoot follows one of the north-northeasterly fissures and was first found on the 300-foot level of the Black Jack near the boundary line, 850 feet east of the shaft. At this point a winze was sunk along the steep west-northwest dip of the fissure and followed the shoot to the 700-foot level. Below this level the dip of the fissure changes to easterly, and explorations are now in progress. There are several parallel shoots or narrow parallel northeasterly fissures; all the shoots pitch northeast.

The ore is siliceous and contains some barite, enargite, and several arsenates, of which olivenite is most abundant. The ore shipped in 1911 contained 0.2 to 0.8 per cent of bismuth, 0.3 to 0.4 per cent of arsenic, 0.2 to 0.7 per cent of antimony, 7 to 10 per cent of iron, and 52 per cent of silica. The principal contents of value were copper, silver, and gold. In 1909 the ore shipped contained 8 to 15 per cent of copper

and 9 to 20 ounces of silver and $1 to $12 gold to the ton.

The Opohonga mine has been in successful operation since 1909 and yielded a heavy tonnage in 1911 and 1912. Up to January, 1913, it had distributed dividends amounting to $72,000.

GOLD CHAIN MINE.

History and developments.—The property of the Gold Chain Mining Co. lies north of the Opohonga and is worked through the old Ajax shaft, sunk to a depth of 1,100 feet. A part of this property was first known as the "Copperopolis and the American Eagle," later as the Ajax mine, and it is described by Tower and Smith under the latter title. The two companies are reported to have produced before 1890 ore to the net value of $1,000,000.

The Ajax Mining Co. continued its operations [1] through the old Ajax shaft to the 1,000-foot level and shipped large amounts of copper ore up to 1907, when 8,091 tons of low-grade ore was shipped from clean-up operations. In 1909 the Ajax, Cleveland, Pedro, and Gold Chain groups of claims were consolidated under the name Gold Chain mines. The shaft was sunk to a depth of 1,100 feet, but up to the end of the year nothing of importance had been found in the lower levels. In 1910 some copper ore containing considerable gold and a little silver was produced. In 1911 shipments were continued and the property was developed to a depth of 1,250 feet. Operations and shipments continued in 1913 and 1914 but were stopped in the later months of 1914. The dividends paid by the Gold Chain mines up to May 25, 1913, amounted to $130,000.

The gross value of the total production of the Ajax and Gold Chain operations since 1899 probably exceeds $3,000,000. The chief value of the ore is in copper, but the ore also contains $5 to $10 in gold and as a rule not more than 10 ounces of silver to the ton.

The shaft is vertical and is sunk from the Ajax tunnel at a point about 400 feet from the portal, the altitude of which is about 6,875 feet, the 1,000-foot level thus about corresponding to the 1,100-foot level in the Black Jack shaft, which lies 850 feet to the south-southwest. The new Gold Chain workings are opened from a winze 220 feet deep from level 10 west of the Ajax shaft and just about vertically below the mouth of the Ajax tunnel.

[1] The following historical notes are taken mainly from the reports of V. C. Heikes in U. S. Geol. Survey Mineral Resources, 1905 and later years.

Geology.—The country rock is mainly the Ajax limestone, but the lower workings probably descend into the Opex dolomite. The Opohonga limestone is exposed on the upper slopes above the mine. The dip of the Opohonga on the surface is 15°–30° NE., and Tower and Smith record a dip of 20° NE. on the 400-foot level. The Ajax limestone is slightly contact metamorphosed.

The most persistent fractures strike north and dip 70° W. to 90°. Others trend northeast and a few N. 55° W.

Ore bodies.—Three ore bodies are opened in this mine—the Hungarian vein, on the west; the Ajax vein; and the Gold Chain vein, on the east.

In the earlier report [2] the following statements are given:

> Just west of the U. S. L. M. No. 1, at the north end of the workings [that is, on the upper levels above the 400-foot level], vein matter is first noted that can be traced continuously to the southern extremity of the mine. * * * The first vein matter is found in a fissure striking N. 35° E. A short distance southwest it intersects a north-south fracture and following this south 75 feet turns into a N. 25° E. fracture, which it follows south 25 feet, only to return to a north-south fracture.

The workings then split, the east branch continuing south for 400 feet with a few offshoots on north-northeasterly fissures, and the west branch continuing south on northerly and north-northeasterly fissures, giving a general direction of N. 10° E.

In the surface workings the mineralization generally extends north with offshoots on north-northeasterly fractures. Down to the 400-foot level the bulk of the ore has been found along the north-northeasterly fractures, though the ore shoot continues as a whole on the northerly fractures.

Mineralization at the intersections of north, northeast, and N. 25° E. fractures has formed large bodies of ore with irregular boundaries, extending in many horizontal shoots along the stratification for considerable distances beyond the main mass of ore.

The ore bodies of the Gold Chain workings lie 700 to 800 feet east of the shaft; they appear to follow a zone of fissures that trends north-

[2] Tower, G. W., jr., and Smith, G. O., op. cit., pp. 744–745.

northeast and is probably the extension of the Opohonga zone, 700 feet to the south. The Gold Chain ore was first discovered on level 3 along a cross break on the Dom Pedro claim that continued east into the Dolly claim, where a fissure striking a little east of north was encountered. The ore body extended from level 3 to level 7, dipped steeply to the east, and is said to have been 400 feet long. The width was generally 15 feet or less but is reported to have reached 50 feet at one place. A raise connects level 7 with level 10, and explorations below level 7 are in progress.

The ores are largely oxidized in the upper levels, almost completely so, according to Tower and Smith. In the lower levels the ore is partly oxidized and carries much enargite and olivenite; the proportion of copper to other metals is unusually large, even larger than in the Mammoth mine, and in places oxidation has segregated the metals in separate bodies.

The ore shipped from the Gold Chain in 1911 showed much quartz, with some barite, enargite, and tennantite. Oxidized minerals were plentiful; among them were olivenite, malachite, tyrolite, conichalcite, and pharmacosiderite.

Some assays of the ore yield 0.6 ounce of gold and 2 to 14 ounces of silver to the ton, 2 to 8 per cent of copper, less than 1 per cent of lead, considerable arsenic, 50 to 70 per cent of silica, 5 to 11 per cent of iron, about 1 per cent of sulphur, 0.5 to 1.7 per cent of zinc, and 7 to 12 per cent of lime.

A third ore-bearing fissure, thought to be the Hungarian vein of the Lower Mammoth, lies to the west of the shaft and the winze mentioned above is sunk on it from level 10. This vein dips west, is about 5 feet wide, and carries lead-silver ore of shipping grade.

LOWER MAMMOTH MINE.

Location and development.—The Lower Mammoth mine lies just south of the town of Mammoth and on the east and southeast is adjoined by the Black Jack property. The mine was opened by tunnel only at the time of the earlier report, and a fissure vein has been found 650 feet from the portal, containing mainly lead and silver.

The altitude of the tunnel is 6,678 feet; the shaft is sunk 650 feet east-southeast from the portal, to a depth of 2,000 feet. The drifts and crosscuts aggregate several thousand feet. The lower Mammoth ground is also opened by a crosscut on the 1,300-foot level of the Black Jack, equal to the 1,000-foot level of the Lower Mammoth, the crosscut reaching both veins.

Water stands a few feet deep on the 2,000-foot level.

Geology.—The country rock is crystalline limestone or dolomite of the Ajax and Opex formations. In part the carbonate rock is strongly contact-metamorphosed, though silicate minerals are rare. The metamorphism does not everywhere seem to be proportionate to the distance from the contact. Where bedding is visible it dips about 20° SE. The principal monzonite contact is crossed by the drifts on the lower levels. A dike 25 feet wide was found in the tunnel 300 feet from the portal, and at 600 feet from the portal there is a zone 20 feet wide of crushed limestone, which is locally called "the dike"; this has apparently no connection with the ore bodies. Very coarse crystalline limestone is found at the shaft on the lower levels, especially in crosscuts toward the west.

Production.—The total production from 1901 to 1916 amounted to 44,493 tons of ore, which yielded 2,046 ounces of gold, 797,022 ounces of silver, 530,797 pounds of copper, 3,902,889 pounds of lead, and 2,105,958 pounds of zinc, having a total gross value of $981,628. Much costly exploration work has been undertaken, and the dividends paid to the end of 1916 amounted to $75,073. The output comprises mostly silver-lead ore and only a little copper and zinc.

Ore bodies.—The operations have disclosed two veins 150 feet apart near the shaft, both striking a few degrees east of north; so far as known they do not continue northward underneath Mammoth Basin. The deposits are distinctly replacement veins, stand nearly vertical, and do not spread widely along other fractures or along stratification planes. Outside of the ore shoots the fissures are inconspicuous and narrow, and many of them branch and include horses of limestone.

The east or Hungarian vein has been opened 300 feet north-northeast of the shaft by a drift from the Copperopolis claim, in the Ajax workings, but apparently without yielding a production.

Old workings from the 300-foot level down to the 1,100-foot level disclosed long, narrow lead

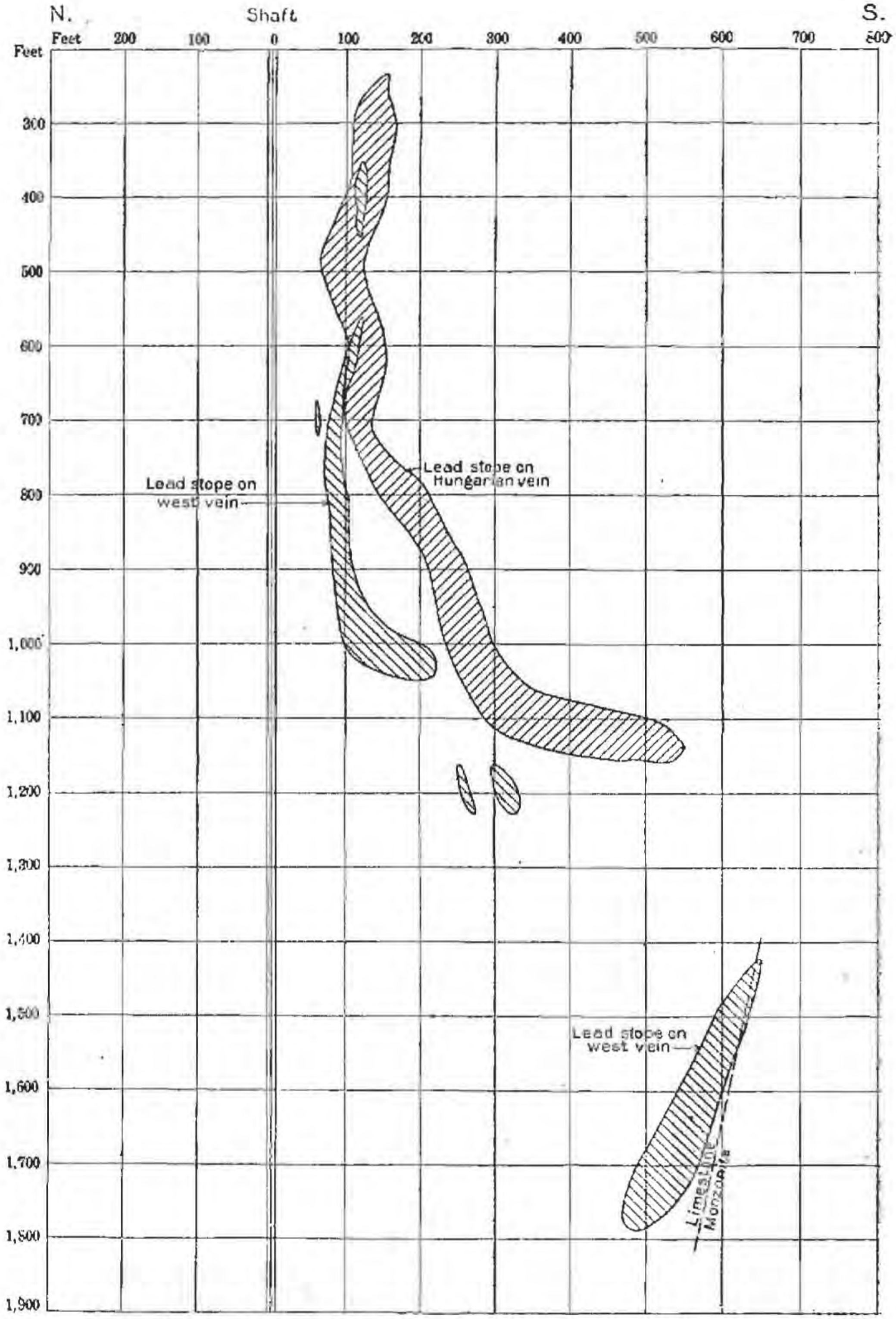


FIGURE 33.—Longitudinal section of lead stopes in Lower Mammoth mine on Hungarian and west veins.

shoots from 5 to 30 feet wide, steep at the top and flattening out below. (See fig. 33.) This deposit is now worked out, and explorations on the 1,500 and 1,700 foot levels have shown little ore below it, though the vein continues well marked, 3 to 5 feet wide, and carries bunches of lead and oxidized copper ore. There are said to be several northerly ore-bearing veins farther east, toward the Black Jack line.

On the west vein, almost opposite the shoot on the Hungarian vein, is another pipelike shoot of lead ore that has been followed from the 400-foot level to the 1,000-foot level, where it flattens out. Small bunches of ore have been found underneath it on the 1,200-foot level. The deeper levels down to 2,000 feet have not shown any large ore bodies below this upper shoot. In depth the vein becomes vertical or dips slightly east.

The largest ore shoot in the mine was found on this vein in the 1,600, 1,700, and 1,800 foot levels, 500 feet south-southeast of the shaft. It is said that the shoot extends from the 1,200-foot to the 1,800-foot level. This shoot, the outline of which is shown in figure 34, has yielded about $200,000 net. Its valuable part lies along the monzonite contact, though the vein cuts through this contact and continues in the monzonite, where it is narrower but still of good value. The vein outside of the shoot is well defined and straight and is marked chiefly by silicification spreading from a narrow fissure; in places there are also limonite and kaolin along the vein. During the writer's visit in 1911 the ore-bearing vein was traced carefully on the 1,700-foot level across the contact and for 50 feet into perfectly normal though soft and pyritic monzonite. Here the vein is 4 to 6 feet wide and contains several heavy stringers of ore.

The ores. —In the lead shoots, which contain a trace of copper, the principal gangue minerals are silica and barite. Small bunches of oxidized copper ores were seen on the east vein on the 1,100-foot level. The large shoot on the west vein at the contact averaged $25 a ton and contained about 20 per cent of lead and 20 ounces of silver and at least 0.05 ounce of gold to the ton. No payment was received for the small copper content. The ore in the monzonite is distinctly different, changing gradually at the contact. It contains much pyrite and zinc blende and a little galena, with some enargite and tetrahedrite, in a gangue of quartz, barite, and, on the 2,000-foot level, a little calcite. One shipment was made of copper ore from the 1,700-foot level, in monzonite, and 35 tons of this ore contained 14 per cent of copper, 42 per cent of insoluble matter, 10 per cent of iron, 3.5 per cent of "speiss" (arsenides), 5.6 per cent of zinc, and 12 ounces of silver to the ton.

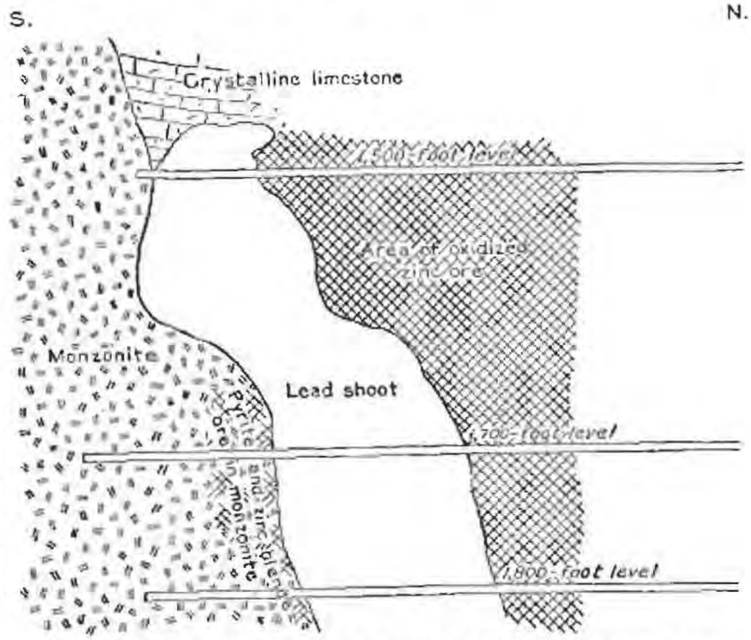


FIGURE 34.—Longitudinal section of stope at contact of monzonite and limestone, Lower Mammoth mine.

The lead ore in the big shoot near the contact was largely oxidized. It contained little zinc, but recent examinations have shown that immediately north of this shoot the altered and clayey limestone contains much zinc carbonate, which in places carried as much as 35 per cent of zinc. This body of secondary zinc ore is no doubt the result of migration from the big shoot under the influence of northward-moving surface waters. Similar bodies of zinc ore have been observed from the 1,300-foot to the 1,800-foot level, extending back along the drift from 50 to 200 feet from the stoped body of lead ore (fig. 34). These bodies are up to 40 feet thick but evidently very irregular. Most of this ore is of

lower grade containing only 10 to 15 per cent of zinc. According to E. R. Zalinski[1] this ore also contains 1.5 ounces of silver and 20 to 30 cents in gold to the ton and 0.5 to 1 per cent of lead. Shipments of ore amounting to 900 tons from the richer part of this ore body have been made.

In the annual report of the company for 1914 the partly developed zinc ore is estimated at 200,000 tons, having an average zinc content of 13 per cent.

[1] Eng. and Min. Jour., June 21, 1913.

BLACK JACK MINE.

Development.—Extensive prospecting operations have been undertaken in the Black Jack mine, owned by Jesse Knight and associates, of Provo, Utah. The shaft is at the head of the southern branch of Mammoth Gulch, at an altitude of 6,964 feet, according to surveys by the owners. It is 1,400 feet deep, and the bottom is dry. A tunnel 2,100 feet long extending north-northwestward starts from Dragon Gulch near the North Star tunnel at an altitude of 6,742 feet and represents the second level of the shaft. The principal levels are about 200, 300, 1,000, 1,300, and 1,400 feet below the surface, the exact altitude of the lowest being 5,584 feet, or 1,380 feet below the collar of the shaft. The total developments amount to 23,770 linear feet.

On the 300-foot level drifts extend 1,300 feet east into Opohonga ground and 600 feet north. The 1,400-foot level extends 1,000 feet southeast and 1,500 feet east. On the 1,000-foot level explorations have also been carried nearly 1,000 feet east. A winze has been sunk to the 1,600-foot level 700 feet southeast of the shaft. The mine was not in operation in 1911 nor in 1914, so that few direct observations could be made. Unfortunately these extensive explorations have not been rewarded by the discovery of many ore bodies.

Geology.—Most of the workings are in the contact-metamorphosed zone of the Opohonga and Ajax limestones, which have a flat easterly dip, but some of the drifts to the west and south undoubtedly cross the monzonite contact. On the 1,400-foot level the main porphyry contact was reached 450 feet southwest of the shaft.

A few cross fissures trending N. 45°–70° E. are exposed; the largest one, which extends east of the shaft on the 1,000-foot level, contains quartz with some silver and gold. A strong northwesterly fissure containing some ore was followed on the 400, 1,300, and 1,400 foot levels and reached Lower Mammoth ground 200 feet northwest of the shaft. This ore carries lead, silver, and a trace of gold, especially near the Lower Mammoth; it is also said to carry pockets of native silver on the 1,300-foot level.

The most pronounced trend of the fissures is north-northeast, with dips of 70° W. to 90°. These fissures form a strong zone a few hundred feet east of the shaft across the Black Jack, Trail, Phoenix, and Opohonga claims, and they pass into the Gold Chain property north of the Opohonga. They have been opened on the 200, 300, 1,400, and 1,600 foot levels. Most of the work is on the 1,400-foot level, on which the fissures have been followed for 700 feet south-southwestward from the Opohonga boundary. Some ore is said to occur along the fissures, and much of the quartz carries some gold and silver; both copper and lead ores are also found.

The limonite deposit a few hundred feet south of the Black Jack shaft is evidently superficial, and it is said that it does not continue down to the 200-foot level, which undercuts it.

MINES OF THE GODIVA ORE ZONE.

A series of large ore bodies extend under the eastern slopes of Godiva Mountain and Mammoth Peak. They begin at the north end of Godiva Mountain with the deposits worked in the Godiva mine; these extended 1,000 feet to the south. A few hundred feet to the east another series of deposits begin in the Uncle Sam claim of the May Day mine[1] and continue south into the Yankee and Old Humbug mines.

At the north end of Godiva Mountain, which is made up of the Pine Canyon limestone, the Packard rhyolite flooded its slopes, and even now, after deep erosion, thick remnants of this flow lie up against the limestone. The entrances to the Godiva and May Day mines are gained through a few hundred feet of rhyolite.

GODIVA MINE.

The Godiva mine is at the north end of Godiva Mountain, and the collar of the shaft

[1] The May Day mine contains workings in the Uncle Sam and the May Day claims, and one of the working shafts was formerly called the Uncle Sam shaft. The workings on the two Humbug claims have been generally known as the Humbug mine, but this mine is now owned by the Uncle Sam Mining Co. and has been renamed the Uncle Sam mine. This is likely to cause confusion unless the facts stated are borne in mind.

has an altitude of 7,025 feet. The depth is about 900 feet, and nine levels are turned; a tunnel intersects the shaft on the 200-foot level. The workings extend almost due north and south, reaching 500 feet north and 700 feet south of the shaft, but do not generally connect with those on the Uncle Sam claim (May Day mine), which lie only 100 to 300 feet to the east. The property was not worked in 1911 nor later except by lessees on a small scale. The total production has not been made public.

The rhyolite and limestone contact lies close to the shaft, and all the lower slopes are occupied by the rhyolite. In several of the workings, notably on the 200, 500, and 600 foot levels, this contact is exposed (p. 180). The rest of the workings are in the Pine Canyon limestone, which strikes about N. 15° W. and dips steeply east. The principal fractures strike north and N. 30° W.

The ore bodies mainly follow the northerly fractures with some offsets along local cross fractures. On the 100-foot level the stopes extend almost continuously for 300 feet north and 500 feet south of the shaft; they trend a few degrees east of north and attain a width of 30 or 40 feet. The ore bodies are also found on the 200, 400, and 500 foot levels below the upper stopes, but they are smaller here and for the present development on the deep levels has ceased. Small and irregular ore bodies were found on the 200 and 400 foot levels respectively 100 and 400 feet west of the shaft.

The ore is largely oxidized and consists mainly of cerusite, anglesite, and galena; it contains comparatively little silver and is said to average 9 ounces to the ton.

TETRO PROPERTY.

The Tetro mine lies a quarter of a mile west-northwest of the Godiva shaft and is not on the line of any recognized channel. It is opened at an altitude of 6,743 feet by a tunnel which for 275 feet passes through rhyolite. (See p. 181.) The Tetro workings connect with those of the Godiva on the 500-foot level by a shaft sunk from the Tetro tunnel. Some mineralized ground showing a little silver has been found but no ore bodies.

MAY DAY MINE.

Development, general character, and production.—The May Day and Uncle Sam claims are now operated by the May Day Mining & Milling Co. They are on the northeastern slope of Godiva Mountain a few hundred feet east of the Godiva mine. In 1911 the property was worked both by the companies and by lessees, twelve sets of lessees being busy between the tunnel levels and the 1,000-foot level.

The mine is opened from the north by the upper and lower Uncle Sam tunnels, at altitudes respectively of 7,115 and 6,931 feet. The Uncle Sam shaft is sunk from the upper tunnel level through the lower tunnel to a depth of 800 feet; below the bottom of this shaft the ground is opened by a winze 300 feet deep. The May Day tunnel has its portal at an altitude of 7,142 feet, 800 feet east-southeast of the Uncle Sam shaft, and 780 feet from this portal the May Day shaft is sunk from the tunnel level to a depth of 500 feet. The workings have a total length of many thousand feet.

The mines are worked on the Godiva channel, which enters the property at the south corner of the May Day claim and branches to the north into the Godiva channel proper and a "new channel" to the east. South of the May Day claim the channel widens in the flat limestone country rock to 200 feet and forms a network of flat, eastward-dipping deposits.

The ore contains mainly lead, silver, and zinc, with only traces of copper. The lead ores are in part oxidized and in part carry galena, but all the zinc ores thus far worked are oxidized.

The production of the May Day from 1901 to 1916 amounted to 95,281 tons of ore, which yielded 6,006 ounces of gold, 901,485 ounces of silver, 4,806 pounds of copper, 25,726,743 pounds of lead, and 5,204,632 pounds of zinc, having a gross value of $2,230,102. In addition to this quantity 15,500 tons of dump material was shipped in 1914, yielding considerable gold and silver. The Uncle Sam and Humbug mines between 1896 and 1916, inclusive, produced 109,905 tons of ore, which yielded 8,575 ounces of gold, 1,869,009 ounces of silver, 17,277 pounds of copper, 213,770,545 pounds of lead, and 384,323 pounds of zinc, having a gross value of $3,266,528. The dividends of the May Day Mining Co. up to 1916, inclusive, amounted to $300,000.

Geology.—On the north and northeast the Packard rhyolite is exposed and rests against the limestone up to an altitude of 7,150 feet, so that the lower Uncle Sam tunnel and the

May Day tunnel enter in rhyolite, but within a short distance they cross the contact. The Uncle Sam shaft is sunk through rhyolite to a depth of 500 feet. The country rock consists chiefly of the Pine Canyon limestone in a part of the Godiva syncline. The dip can not everywhere be ascertained, but it ranges generally from 20°-30° E. or NE. Below the Pine Canyon limestone the workings enter the Gardner dolomite, which contains lenses of black shale.

The only intrusive body thus far found in the limestone in these workings is a dike of rhyolite along the east channel. On level 5 it lies 200 feet west of the shaft and is 15 feet wide; it has been followed for 300 feet, and toward the south the width increases to 100 feet. The same dike is found on the 200 and 300 foot levels. In the tunnel this dike has been followed for about 800 feet. The dike dips steeply to the east, and the ore of the east channel lies in general below it.

The mine is in general dry, even in the deepest workings, but along the contacts of rhyolite and limestone there is a considerable seepage of water, rich in sulphates and unfit to drink.

Uncle Sam workings (May Day mine).—The upper tunnel, the portal of which is at the shaft, altitude 7,115 feet), is long and contains many of the earlier workings. About 350 feet southwest of the Uncle Sam shaft the crosscut reaches the line of the Godiva channel, which here trends northwest. The workings extend more or less continuously for 500 feet southeast of this point. The level extends 800 feet farther south into unproductive territory and then bends east for a few hundred feet to reach the flat workings in the Humbug claim, also on the Godiva channel. These workings are in part on the level of the Uncle Sam tunnel but mainly on the Yankee tunnel level (altitude 7,019 feet).

The old workings on the west channel evidently followed fractures extending north or north-northwesterly. One of the stopes is 100 feet long and as much as 40 feet wide and extended at most 200 feet below the tunnel level. The ore bodies reached up within 60 to 100 feet of the surface—that is, about 200 feet above the tunnel level—where they were irregular, steeply dipping shoots cutting the stratification and having a vertical extent of about 400 feet. Some galena ore was extracted from the tunnel level in 1911.

Tower and Smith[1] refer to one of the deposits as an irregular chimney, whose greatest width was 4 to 6 feet. Its course was north to northwest, and it pitched southeast at an angle of 50°. The ore, according to these authors, contained little but galena, 2,000 tons averaging 65.5 per cent of lead, 2 per cent of iron, and 4 per cent of zinc, the zinc probably in the form of oxidized minerals. The ore shoots are sharply outlined, and the surrounding limestone is little altered.

Deeper workings.—The explorations on the deeper levels from the Uncle Sam shaft have failed to discover other ore bodies. On the Godiva channel small stopes are shown on the 275-foot level.

The principal workings of the lower levels are on the "east channel," which crosses the claim diagonally, trending north or north-northwest. The ore bodies are best seen on the 275 and 500 foot levels. A dike of porphyry lies along this channel; on the 500-foot level it first appears 200 feet southwest of the shaft and can be traced for 300 feet. The dike dips east at a steep angle, and the ore bodies lie below it. On the 500-foot level some galena ore is found along the dike, and below this lies some gold ore with much oxidized material containing iron and manganese.

At the Uncle Sam shaft on the 700-foot level the limestone is brecciated and silicified, but this fractured zone is not in line with any known ore channel. This wide body of siliceous rock continues north-northeasterly for 350 feet from the shaft, and a winze has been sunk in it to a depth of 75 feet. In places this material contains a little silver.

On the 800-foot level extensive explorations have been carried out underneath the upper ore bodies. The country rock is the Gardner dolomite, lying underneath the Pine Canyon limestone, and the prevalent dip is 25° NE. About 350 feet north of the shaft a pipe of galena ore has been opened, and similar ore has been picked up from a winze going down to the 1,100-foot level, the lowest in the mine. This is on the easterly branch of the Godiva channel.

May Day workings.—The May Day claim has been worked from the May Day shaft (altitude of collar 7,655 feet), which is 500 feet deep, but it is now opened from the Uncle Sam shaft. A number of eastward-dipping,

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 750.

nearly flat ore bodies of galena have been worked here from above the 100-foot level down to the 400-foot level; they represent the northward continuation of the Godiva channel. On the whole the ore bodies pitch to the north.

In 1911 oxidized zinc ores began to be extracted in the May Day claim. The stopes then seen were on the 300-foot level, 100 feet below the lower tunnel, along the east channel. The zinc carbonate was lying below the lead stopes and formed masses of replaced limestone 4 to 5 feet thick. The ore contained about 30 per cent of zinc and 1 ounce of silver to the ton; there was no gold and little galena. The change from galena to oxidized zinc ore took place gradually, and where lead and zinc were mixed the ore contained more silver than elsewhere. The lead shoots along the east channel were from 18 to 30 feet wide and contained heavy galena ore, mostly taken out about 1905. The mining of oxidized zinc ores has continued, and in 1913 Mr. Loughlin obtained the following data bearing on their occurrence:

Zinc ores of the May Day mine.—The oxidized zinc ores of the May Day mine thus far worked lie both vertically beneath and also down the dip from oxidized lead stopes between the 200 and 500 foot levels. Their general outlines are roughly parallel to those of the lead stopes, but offshoots from them extend for short distances along prominent cross fissures. The main stopes at these cross fissures have greater than the average thickness. In some places the lower and only partly oxidized margin of a lead stope merges into the upper part of an oxidized zinc ore body, and galena is mingled with smithsonite and more or less calamine. Any zinc blende originally present with the galena in these places has been removed. In fact, no zinc blende has ever been noticed anywhere in the mine. This mixed galena-smithsonite ore forms locally the hanging wall of the (purely) zinc ore. Other bodies of high-grade zinc ore, including the most valuable one, are found at considerable distances from the lead stopes, though connected with them by fissures and by pipes of zinc ore.

The zinc ore is found both in numerous small bodies along fissures and bedding planes and also in larger replacement bodies of irregular outline. (See fig. 23, *F*, p. 172.) The smaller bodies are chiefly fillings or partial fillings without any conspicuous amount of replacement, along fractures or open bedding planes, and are quite as numerous in the hard fine-grained cherty limestone as in the coarse-grained limestone. The cherty limestone has in some places, where numerous open bedding planes or fractures made conditions favorable, undergone distinct replacement, leaving unreplaced chert nodules in the ore, but such replacement bodies are small and lie close to the openings. Intersections of fissures with one another, with open bedding planes, or with relatively permeable beds, as well as local openings along bedding planes of a permeable bed, have provided favorable places for the formation of pipes of zinc ore. The ore in such pipes may have so completely filled the openings and replaced the adjacent rock that traces of the courses followed by the waters depositing the ore are concealed, and the origin of some of the pipes would be a puzzle so far as evidence concerning them alone is concerned.

The larger replacement bodies are, so far as it has been possible to study their walls, developed in the coarse-grained limestone. The largest body, which has thus far yielded most of the May Day zinc ore and which is now stoped out, is of generally rounded outline (fig. 23, *F*) and extends for a considerable distance across the bedding, suggesting that practically complete replacement had occurred in a place where the coarse limestone was rendered especially permeable by fracturing and the openness of bedding planes. Offshoots from this large body follow bedding planes down the dip, either between coarse-grained strata or between a thin fine-grained and a coarse-grained bed. Other replacement bodies were seen to end abruptly against limestone, save for a few thin layers that continued along the more open bedding planes.

The zinc ore was discovered on the tunnel level in the footwall of a lead stope and was followed downward along pipes and irregular veinlike bodies nearly to the 400-foot level, where it opened into the large body. The large body diminished downward to a thin streak, 1 foot or less thick, which when seen (June 5, 1913) was being followed along a bedding plane.

Lead carbonate stopes have been worked below the 500-foot level, but no systematic

prospecting around them for associated zinc ore had been undertaken up to June, 1913.

Three distinct varieties of the ore have been mined—brown, iron-stained massive ore, mostly limited to the upper stopes; black, manganese-stained ore, found mostly in the bottom of the zinc workings; and the gray, unstained ore that has been found throughout the zinc workings.

Gold ores.—Some of the iron-stained soft material 1 to 2 feet thick lying underneath the lead stopes in the May Day claim contains $30 to $70 a ton in gold and was mined in 1911; this ore contains only 1½ per cent of lead, probably in oxidized form. The lead stopes are as much as 20 feet wide and are in general on the beds that dip at moderate angles to the east.

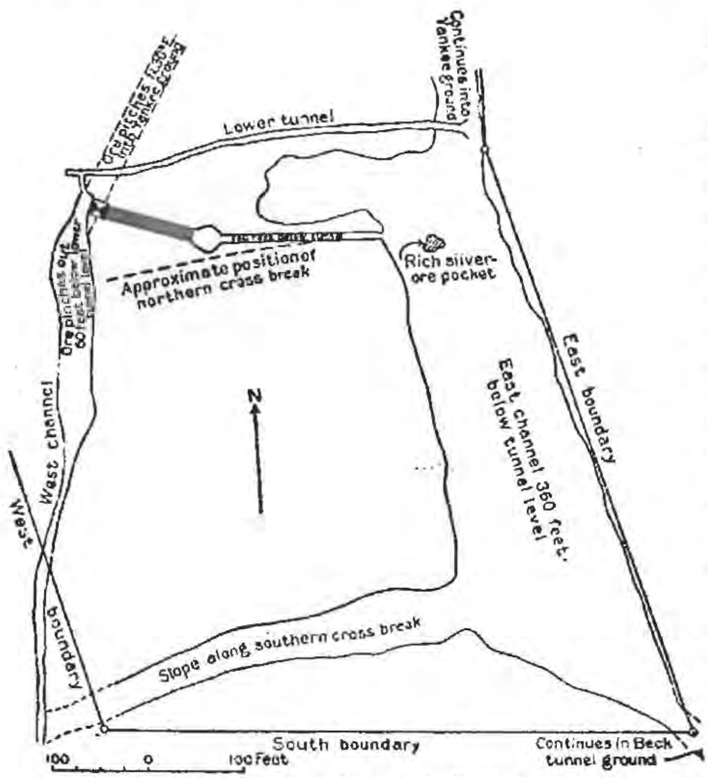


FIGURE 35.—Plan of workings near the Humbug tunnel.

GODIVA CHANNEL IN THE HUMBUG AND YANKEE CLAIMS (UNCLE SAM AND YANKEE MINES).

The Godiva channel leaves the May Day claim at its southeast corner, where lead stopes 25 feet wide were mined on the 100-foot level from the old May Day shaft. Underneath some of these bodies of galena gold ore was found, consisting of a red or brown oxidized material. The ore channel owes its position to the intersection of a series of northerly fractures with limestone beds suitable for replacement. From the point mentioned it has been traced more or less continuously through the Yankee and Humbug claims for 1,300 feet to a point on the easterly dislocation which about coincides with the westward extension of the Bullion Beck tunnel, and from this point the channel is more or less continuous southward to the Northern Spy, Carisa, and North Star, a distance of about 10,000 feet.

The workings in the Humbug and Yankee claims occupy a width (in horizontal projection) of 100 to 300 feet and a length of about 1,000 feet. (See fig. 35.) They are chiefly on the Yankee tunnel level (altitude 7,010 feet) and the Uncle Sam upper tunnel level of the May Day mine (altitude 7,105 feet), though some of them descend 200 feet below the Yankee tunnel. The individual deposits reach 200 or 300 feet in length in a general northerly direction and are usually a few feet thick. Their origin is undoubtedly connected with narrow northerly fissures in the limestone, but the deposits themselves follow the flat bedding. Their lateral extent is rarely above 50 feet.

The Yankee tunnel extends through rhyolite for 300 feet from the portal and then enters the Humbug formation, which here is nearly flat. (See section A–A′, Pl. V.) Before reaching the ore bodies the upper members of the Pine Canyon formation are cut, and the ore is probably wholly in this formation. The dip of the strata is 10°–30° E.

The ore bodies opened by the Yankee tunnel have been found in three "channels"—the east, west, and middle—all connected by pipes. The east and west channels are the same that have been described under the heading "May Day mine." They both follow distinct fissure-like northerly courses across the greater part of the property, the ore bodies lying mostly in horizontal position, with here and there a downward pitch to the north-northeast (diagonally along eastward-dipping beds) between two horizontal portions. This attitude continues to a point southeast of the May Day's southeast corner, where both channels turn northwestward, following gently dipping beds of coarse-

grained limestone, and are continuous with the flat stopes of the May Day. The bottom of the west channel shoot lies along the roof of the 300-foot level. At the May Day line it extends upward in pipe form, trending N. 45° E., presumably along a cross break, and connects with the middle and east channels, meeting the latter at the 225-foot level.

The middle channel extends southeastward from this northeastward-trending pipe at the May Day line for 700 feet and pinches out before reaching the south boundary of the Yankee ground. Its top is level with the bottom of the east channel and lies 75 feet farther west.

The west channel contained two rich shoots, one at the Humbug claim line (No. 5 stope) and one near the May Day line (Jewel Box stope); the latter was at the top or upper ends of the ore bodies. The minerals in these rich shoots were chiefly horn silver and cerusite, with a little galena and a quartz gangue. The silver content ran up to 50 ounces to the ton. The ends of the ore bodies, on both north and south, were in quartz, but the sides were in vuggy limestone and were not sharply defined.

The east and middle channels had no extra rich shoots, but their good ores were practically continuous and gave higher returns. The ore of the middle channel averaged a little better than that in the east and west channels. The ore in the main ore bodies was a mixture of galena and cerusite. Smithsonite and calamine formed a bottom casing to the lead-silver ore.

The principal workings on the Humbug claims consist of a main tunnel (the "lower tunnel") at an altitude of 7,355 feet, which extends into the mountain about 450 feet and is connected by two winzes with three sets of drifts along the ore bodies, on the tunnel level and 260 and 460 feet below the tunnel. Two short tunnels, the middle and upper, reach ore above the main lower tunnel, and are connected with the main tunnel by a chimney-like stope. The surface rock is the Humbug formation, but the ore is found wholly in the upper beds of the underlying Pine Canyon limestone, the top of which is cut 300 feet from the mouth of the lower tunnel and 160 feet from the mouth of the middle tunnel. The strike of the limestone is north; the dip is 60° E. or steeper along the western workings but flattens to 30° E. along the eastern workings. Ore is confined to the easily replaceable coarse-grained limestone beds, where they are cut by northerly mineralized fissures. A fine-grained to dense cherty bed forms the exact or approximate footwall in places but appears to have been impervious to the mineralizing solutions. The covering of débris on the surface prevents an accurate determination of easterly or northeasterly faulting, but a fault trending N. 70°–80° E., shown on the crest of Godiva Mountain by an offset of nearly 200 feet and approximately indicated by an offset in the boundary of the Humbug formation, is in line with a cross break in the mine. A second cross break, also trending N. 70°–80° E. but with no proved displacement, extends across the south end of the property within 20 or 30 feet of the southwest corner. Fractures exposed underground trend north, east, and northeast.

The ore lies in two main bodies, the east and west channels, which may be connected along a cross break close to the south boundary of the property. The west channel or vein is a part of the mineralized zone which has been opened continuously from the Carisa to the Godiva. It enters the Uncle Sam ground about 160 feet north of the southwest corner of the property (Humbug No. 1 claim) and follows an average course of N. 10° E. as far as the main tunnel, where it swings to a N. 30° E. direction and passes into Yankee ground. Its dip is about 60° E. The workings throughout the greater part of the west channel were not accessible at the time of visit. Ore in the west channel is continuous horizontally from a point 100 feet north of the property line into the Yankee workings and extends down the dip to a point 60 feet below the main tunnel, a total of 100 feet. The top of the shoot was discovered close to the surface, where it is covered by 10 or 12 feet of cemented limestone talus. The shoot extends downward in the form of a pipe for about 70 feet and merges into the vein proper. The pipe lies approximately in line with the northern cross break. The upper 50 feet of the pipe contained horn silver (and argentite?), with little or no lead, in highly fractured limestone full of small vugs lined with colorless flat calcite rhombs. The silver was confined to a loose yellowish-brown sand in or beside the vugs, the inclosing limestone assaying no more than a trace of silver.

Quartz was practically absent. This ore was at first thrown on the dump, but in 1911 it was being screened and shipped. At the 50-foot depth lead, mostly the carbonate, with a little galena, became conspicuous, and farther down it gradually increased in quantity. At a depth of 70 feet the pipe merged into the main vein and quartz became the prominent gangue mineral. According to the earlier report [1] barite was present in the gangue, but there was so little copper that no allowance was made for it in the market.

The pay shoot in the west vein north of the pipe lies parallel to the strike and dip of the country rock and pitches N. 30° E., as if along the intersection of an eastward-dipping fissure with the coarse-grained limestone. South of the pipe and of the northern cross break the vein trends more nearly N. 10° E. and the pay shoot has a more nearly horizontal position, coinciding with the intersection of the fissures and the bed, whose strike is practically due north. The pay shoot here pinches 60 feet below the main (lower) tunnel level, presumably where the 60° dip carries the bed away from the more nearly vertical fissure. The pay shoot in some places lies wholly within the coarse-grained limestone and in others lies against a footwall of the dense black cherty limestone, but the exact location of these places was not learned.

The east channel also lies parallel to the bedding of the coarse-grained limestone, which here strikes north to N. 10° W. and dips 30° E. Whether the west and east channels lie on the same bed displaced by faulting or on similar parallel beds could not be determined, but from the northward convergence of the two channels their location on the same bed seems probable. The trend of the east channel is about due south from the Yankee workings as far as the northern cross break. Here it sends a branch, 50 to 60 feet wide, upward to the west with a dip of 45°–50° E. for a vertical distance of 270 feet, its highest point lying about 130 feet below the base of the west channel, which is about 150 feet farther west. Near the junction of the branch with the main east channel was found a concentration of horn silver and argentite in pipe form measuring 50 by 20 by 4 feet, which yielded $100,000.

The trend of the east channel between the north and south cross breaks, a distance of nearly 400 feet, is about N. 10° W. Its average width along the dip is over 100 feet and its thickness 7 or 8 feet. At the southern cross break a second branch about 40 feet wide and extending upward in a S. 80° W. direction has been stoped for 300 feet or more and may join with the west channel, which lies about 100 feet farther west. This branch shoot has yielded $500,000, half of which was paid as dividends. The ore is said to have been chiefly fine steel galena with much silver in the upper portion and silver-bearing cerusite (lead carbonate) in the lower portion, with a quartz gangue.

At its junction with the southern cross break the east channel widens to 150 feet, assumes a S. 63° E. strike along a bed dipping 30° E., and passes through the southeast corner of the Uncle Sam into the Beck Tunnel ground. The workings are wholly in the coarse-grained limestone.

The ore that was mined in the east channel during the writer's visit consisted of galena, rather coarsely crystallized, and cerusite in a gangue of mixed dark and white quartz. The white quartz is of later origin than the dark and appears to accompany the ore minerals. The dark quartz was said to be lean.

The output has all been silver and lead. No zinc has been reported, but it would not be surprising if some were found at the bottom of the stopes beneath the lead ore.

ORE IN THE MAY DAY, HUMBUG, AND YANKEE WORKINGS.

The ore extracted from the May Day and Yankee workings consists largely of galena, which is only partly oxidized. It is not very rich in silver, containing at most 30 ounces to the ton. In the workings on the Yankee and Uncle Sam (Humbug) ground the lead ore may average 30 per cent lead and 55 per cent of insoluble matter, largely silica. The ore contains only traces of copper and very little barite. Some barite is reported from the ore on the Humbug claims. The gangue is fine-grained dark and white quartz. Gold ore has lately been found in the May Day claim underneath the galena. This ore is soft, red, and oxidized; it contains much iron and manganese and as much as 2 ounces of gold to the ton, though it averages considerably less.

The lead ore contains but little zinc and no sulphide of zinc has been found in these work-

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 750.

ings. The zinc sulphides have been oxidized, and the easily soluble sulphate has effected large replacements of limestone near the lead stopes. The zinc carbonate ore contains at most 1 ounce of silver to the ton and usually 30 per cent of zinc.

Exploration in the Uncle Joe claim, which is owned by the Chief Consolidated Mining Co., from the May Day mine has recently resulted in the discovery of considerable bodies of lead-silver ore which probably form a southerly branch of the Godiva channel.

In the southern part of the Humbug claim the ore of the upper workings was largely oxidized and some of the bodies contained much horn silver; lower down coarse galena was found. These bodies lie parallel to the slope of Godiva Mountain and not far underneath the surface. A little copper is contained in the Humbug and Yankee ore bodies, and the ore also yields $2 or $3 in gold to the ton.

YANKEE MINE.

The Yankee mine, owned by the Yankee Consolidated Mining Co., is on the east slope of Godiva Mountain north of the Uncle Sam property. Its office, tunnel adit, and shaft are close by the wagon road about a third of a mile south of Knightville. The larger stopes, which are near the surface and connect with those of the Humbug claim, are now practically exhausted. They yielded first-class ore running 28 to 30 ounces or rarely as high as 50 ounces to the ton in silver and 25 to 30 per cent in lead and second-class ore running 10 ounces in silver and 10 to 15 per cent in lead. Besides these two grades, a low-grade milling ore that remained in the dump for some years found a market in 1911. Ore is hauled by wagon to the Denver & Rio Grande Railroad at Summit station. In 1912, considerable shipments of zinc ore, which underlies the silver-lead stopes, were begun.

The underground workings consist of a shaft 2,000 feet deep and a tunnel which is connected by an inclined winze with levels down to a vertical depth of 500 feet below it (600 feet below the collar of the shaft). The stopes do not extend below this 600-foot level. Prospect drifts from the shafts have been or are being run on the 700, 900, 1,300, 1,400, 1,700, 1,900, and 2,000 foot levels.

The country rocks include the Packard rhyolite, the Humbug formation, and the coarse-grained and dense cherty beds of the Pine Canyon limestone. The rhyolite forms the eastern part of the surface rock, its west boundary lying about 90 feet west of the shaft. The shaft passes through rhyolite nearly to the 300-foot level, and the rhyolite contact on this level is cut about 30 feet northeast of the shaft, striking N. 10° W. and dipping 50° E. Another "porphyry" contact dipping 70° W. is said to be exposed at the east end of the 600-foot level but was inaccessible during the writer's visit. The rhyolite, as in the neighboring mines, is strongly impregnated with pyrite and, where exposed underground, is coated with fine feathery crystals of iron sulphate.

The Humbug formation is the surface rock west of the rhyolite and is cut by the tunnel as far as the two short crosscuts that reach the top of the east-channel ore shoot. Its dip, as exposed in the tunnel, is nearly or quite flat (not over 20° E.) and proves it to be close to the synclinal axis concealed beneath the rhyolite. The true strike could not be measured but follows a north-northwest to northwest direction. Several open vertical fissures trending N. 15° E. are cut along the tunnel in the Humbug formation. The Pine Canyon limestone does not reach the surface of the property, but its upper portion contains all the ore shoots thus far found, the shoots extending from its upper contact at the tunnel level (about 100 feet below the shaft collar) to the 300-foot level, an approximate vertical distance of 200 feet.

The alternating bluish-gray coarse-grained and dense black cherty beds with an occasional light-gray fine-grained bed persist to about the 1,300-foot level, where the workings expose the black carbonaceous bed, here 100 feet thick, that marks the top of the Gardner dolomite. A watercourse was struck along this bed, yielding 2,000 gallons in 24 hours, but the water is now piped down to the bottom of the shaft, where it disappears. Another bed of similar character but much thinner is exposed on the 1,800-foot level. The 2,000-foot level cuts a coarse-grained bed, partly dolomitized, which may be the same as the coarse-grained dolomitized bed near the base of the Gardner dolomite on the flat-topped spur west of Gardner Canyon.

Fissures trending about N. 15° E., many of them open or widened into small caves, are numerous, but no conspicuous faults have been proved. On the 300-foot level 300 feet southwest of the shaft is a cave about 100 feet long and 20 feet high, whose major axis pitches 30° or more in a northerly direction. Vein quartz, brecciated and recemented, lies along its east wall. At the 930-foot level at the shaft is another large cave which pitches about 35° NNE. When visited it was largely filled with waste from the lower workings (Pl. XXXIV), but its original depth is said to have been at least 75 feet. Its roof is the black cherty thin-bedded blocky limestone, which evidently collapsed after the dissolution of some underlying bed, leaving a jagged surface with no marks of corrosion. The shaft passes for 300 feet downward from the cave through loose rock to a point about 60 feet above the 1,300-foot level, where it passes into coarse-grained gray limestone.

The workings of the Yankee mine on the Godiva channel are described on page 228. The prospecting operations from the deep shaft had for their purpose the discovery of the northward continuation of the Iron Blossom channel.

Prospecting on the 400, 500, and 600 foot levels has found a few quartz veins of very low value but thus far nothing of commercial grade. The south drift on the 600-foot level follows a fissure containing quartz and limonite. This fissure is vertical for some distance, flattens to a dip of 45°, which it follows upward to the 550-foot level, and resumes a vertical course southward. A narrow quartz vein, 2 to 3 inches wide, is said to follow the porphyry dike contact (now inaccessible) at the east end of the 500-foot level. It carries a little gold and silver but no lead. About 200 feet south of the vertical shaft a drift follows a nearly north-south fissure which carries black quartz with a little pyrite, copper stain, and a trace of lead. Its assays ran 40 to 60 cents in gold and half an ounce to 1½ ounces in silver to the ton. What is probably the same vein is cut on the 400-foot level, 200 feet west of the shaft. It dips 60° NE. and has been followed upward for 100 feet. The south drift on the 400-foot level, 100 feet west of the shaft, follows a narrow vein of dark quartz which is brecciated and recemented by white milky quartz. It has been followed for 500 feet in a northerly direction stopping against the soft decomposed porphyry contact. It assays $1 in gold, and 1 ounce (average) in silver to the ton but contains no lead. Farther west brecciated quartz of the same type lies along the east side of the cave on the 400-foot level.

Since the mine was visited a mineralized quartz zone on the 1,900-foot level yielding low assays in lead, silver, copper, and gold, with iron and manganese, has been reported, and similar material without the copper has been found on the 1,800-foot level.[1] A prospect drift on the 2,000-foot level, headed for the ground beneath the gulch east of the shaft, to cut what is locally known as the Great Eastern vein (Iron Blossom?), has also exposed a vein of quartz, barite, and some calcite, with iron and manganese oxides and small quantities of lead, silver, gold, and copper. Assays show an average of 8 ounces of silver and 80 cents in gold to the ton, with occasionally as high as 112 ounces of silver and $18 in gold. These local rich spots show prominent stains of malachite and azurite, but the copper content is said to be only 0.5 per cent. The vein ranges from a mere streak to 4 feet and follows an approximately east-west break.

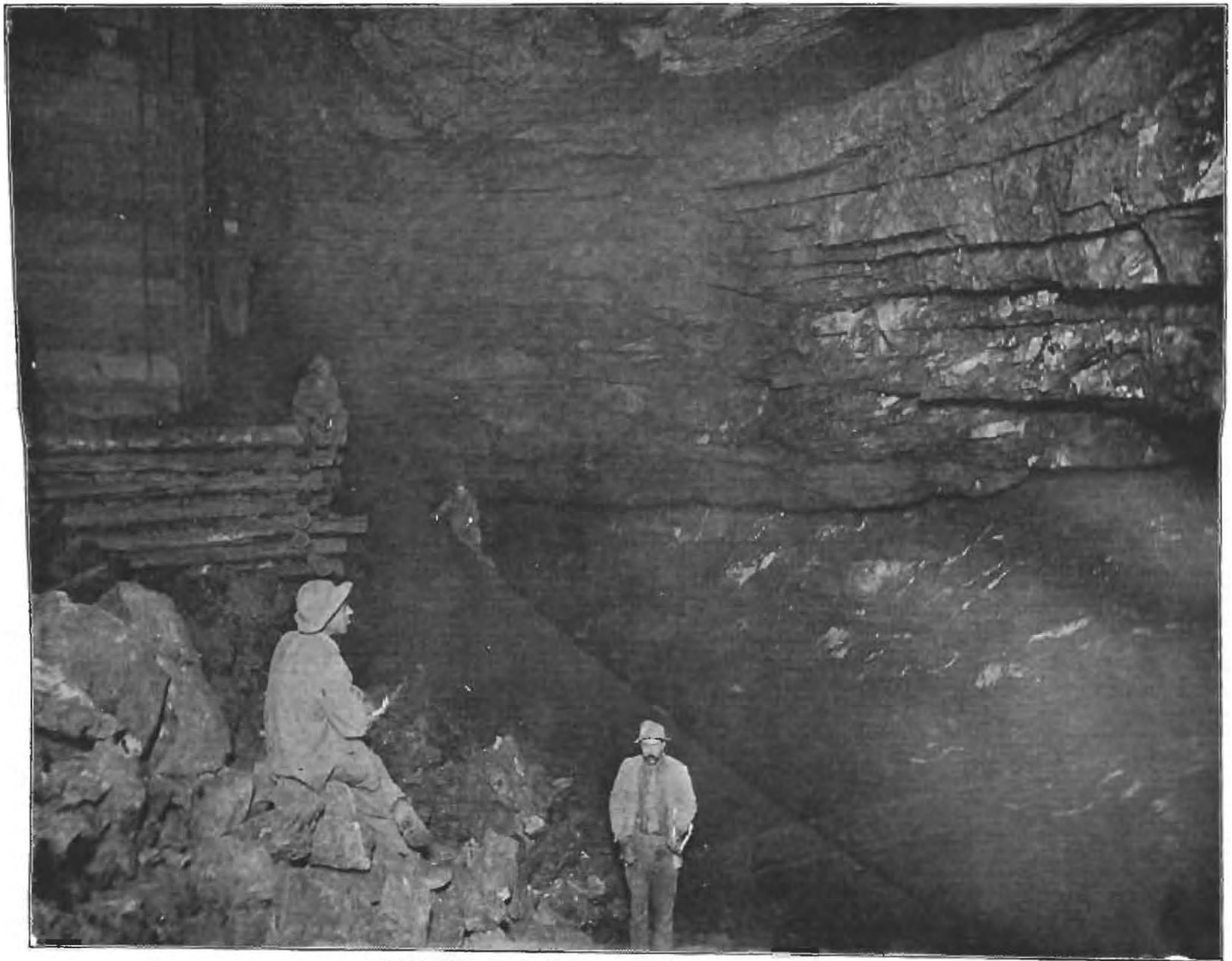
UTAH AND SIOUX MINES.

From the Humbug tunnels southward to the Northern Spy, a distance of 2,500 feet, the Godiva ore zone has been followed more or less continuously. It has been worked from the Utah tunnel (altitude 7,318 feet) and the Sioux tunnel (altitude 7,327 feet). Little work has been done along this line since the report of Tower and Smith was issued, and that report contains most of the available information. The beds strike north, and the average dip along the ore zone is 45° E.; toward the west the dip steepens to 90° and toward the east it lessens to 25° or even becomes horizontal. The best section is shown in the Sioux tunnel, which at 370 feet from the portal intersects the Humbug formation of limestone and sandstone; beneath this it enters coarse light-blue limestone of the Pine Canyon formation and reaches the ore body about 550 feet from the portal.

The principal fractures, which are generally vertical, trend north, N. 15° E., N. 30° W., and east.

The ore body is a flat shoot which rises gradually from the Sioux and Utah tunnels to a cul-

[1] Manager's report, printed in Salt Lake Min. Rev., Feb. 15, 1613.



LIMESTONE CAVE CUT BY SHAFT OF YANKEE MINE.
Photograph by R. M. Kellogg.

minating point 200 feet above the tunnels and between them. South of the Sioux tunnel it keeps on the level of that opening. It follows generally a northerly direction; at many places it is offset on other fractures, but prevailingly to northerly planes. Where it follows such planes the ore body has generally a rather low dip to the east, but on cross fissures it is nearly vertical. The ore bodies of low dip are mainly parallel to the bedding. Presumably the ore solutions ascended in northward-trending fissures, but these have not yet been found. The ore body is from 2 to 50 feet wide and forms chambers or irregular masses parallel to the stratification or the fissuring.

The ore is largely oxidized but contains some galena. The gangue minerals are quartz and barite. Some copper is present as enargite and oxidized minerals, also a little gold. Banding by barite and quartz is mentioned by Tower and Smith, who also state that quartz is most abundant in the centers of the ore bodies and that the metallic minerals occur mainly next to the walls.

No explorations in depth appear to have been undertaken in these mines.

NORTHERN SPY AND CARISA MINES.

Developments.—The Northern Spy and Carisa mines are now worked together by the Carisa Mining Co. The only connection between the two mines, however, is on the 700-foot level. The two properties lie on the east and southeast slopes of Mammoth Peak, the Northern Spy shaft at an altitude of 7,390 feet and the Carisa of 7,530 feet. The Northern Spy shaft is due south of the Humbug and Utah tunnels and 3,700 feet distant from the Utah. Its depth is 900 feet and the drifts are of great aggregate length. Much prospecting work has been undertaken on levels 7, 8, and 9, but no large ore bodies have been found.

The Carisa shaft lies 1,050 feet south-southwest of the Northern Spy shaft. The water stands knee deep in the ninth level, 800 feet below the surface. The long Sioux-Ajax tunnel connects with level 7 of the Northern Spy mine.

Since 1911 little work has been done in these properties. In 1911 prospecting was in progress under the management of Grant Snyder.

The two properties have yielded lead, silver, copper, and gold, but the total production has not been made public. The dividends of the Carisa Co. amount to $60,000, and the last distribution was made in 1906.

Geology.—The geologic conditions near the Spy mine are somewhat complicated. A few hundred feet north of the shaft the Humbug formation ceases, and immediately north and above the shaft, the Pine Canyon limestone is exposed, dipping about 20° NNE. On the 500-foot level the underlying Gardner dolomite is exposed, the characteristic black carbonaceous bed of the uppermost Gardner lying 25 feet above the level northwest of the shaft.

The area south of the shaft contains beds of the Bluebell dolomite. These beds have about the same dip as those to the north of the shaft—20° NNE.

A considerable dislocation, known as the Sioux-Ajax fault, separates the two areas and antedates the mineralization. The vertical downthrow on the north side is not less than 1,500 feet. The fault is probably almost vertical, but the throw is thought to be distributed on several planes. Owing to the massive bedding it is difficult to place the fault accurately in the mine workings. There has been much silicification at the intersection of the fault with the ore-bearing fissures, and the fault fissures are not conspicuous. Although the general course of the ore channel was not interrupted by the fault, the ore bodies north of it present a strong contrast to those on the south.

A few hundred feet east of the Carisa shaft an irregular mass of monzonite is contained in the Bluebell dolomite, which, in its vicinity, is strongly though irregularly marbleized. This small monzonite stock has been reached by the Joseph crosscut from the Carisa shaft, and two southward apophyses of it are cut by the Carisa tunnel. A northerly offshoot of the same body has been opened by crosscuts on levels 4, 6, and 7 from the Northern Spy shaft; it trends north, is as much as 80 feet wide, and lies 300 to 400 feet east or east-northeast of the shaft. This dike has no special influence on the mineralization. The porphyry contains finely distributed pyrite; on the contact on level 4 there has been some mineralization, and oxidized iron and manganese minerals appear in considerable quantity. It is stated that this material gives maximum assays of 2 ounces of silver and 40

cents in gold to the ton. On level 7 the dike is 80 feet wide and is 450 feet northeast of the shaft. The dike is not continuous, for immediately below this place on level 9 no intrusive rock was found. A large open cave was found on level 7 and extended about 150 feet below it. This cave was probably caused by solution following brecciation effected by faulting. Oxidized copper ore was found in the vicinity of the cave.

Ore bodies.—North of the shaft a flat lead stope extends for about 250 feet, or to the "old shaft," on the 100-foot level. Beyond this point prospecting operations have extended for 350 feet toward the Sioux workings. This ore body, which was mined long ago, was similar in occurrence to those found in the Humbug, Utah, and Sioux properties—that is, it it was formed by replacement in a coarse-grained bed of the upper part of the Pine Canyon limestone along its intersection with a vertical fissure, which here trends about N. 20° E. The ore contained galena and cerusite and was fairly rich in silver. South of the shaft and the fault the ore bodies follow the fissures instead of the planes of stratification. The ores contain much copper, originally as enargite but now partly oxidized; they also carry much barite. The fissures which carry the ore are in themselves inconspicuous, the ore spreading from them by replacement of the dolomite.

Oxidized copper ores cropped out about 400 feet south of the shaft along several fissures. These upper stopes did not continue down to level 4. The principal fissures trend N. 20° E. and are nearly vertical. On level 6, 540 feet below the surface, near the shaft, a body of copper ore was found, which continued down to and below level 7; the ore yielded 12 per cent of copper, much iron, little silver, and very little gold. In great part it was oxidized and contained copper arsenates in honeycombed quartz with some copper carbonates replacing dolomite. The ore contained no lead, but at the north end, just about at the fault, 1 ton of galena ore was found in the shoot. Silicified dolomite or limestone surrounds the shoot.

Exploratory crosscuts to the east side line, which is near the Iron Blossom ore shoot, disclosed much "vein matter and silicified limestone" with low gold content.

Carisa mine.—The Carisa workings are contained in the Bluebell dolomite, perhaps also in the Gardner dolomite, and the rocks are partly marbleized to a white coarse-grained rock known locally as the "Carisa lime." The direction of the dip is difficult to ascertain. Shallow workings on copper ore have been opened in the northern part of the property near the Northern Spy boundary line. The principal ore body was mined from the surface down to level 7. It follows a fissure that trends N. 20° E. The shoot is vertical at the surface and then pitches 45°–60° S.; at the deepest level (the ninth, equal to a depth of 800 feet) it crossed the Boss Tweed and Victor end lines, about at the boundary line between the two. It did not, however, continue far down into these properties. This shoot or pipe had a length of 500 feet in horizontal projection and was at the most 50 feet wide. The ore was siliceous, containing gold, silver, and copper, and is said to have had a value of $60 a ton. In part it contained unoxidized enargite. Some of the rich ore is said to have contained 3 to 4 ounces of gold and 25 ounces of silver to the ton and 10 per cent of copper.

Tower and Smith[1] state that above the 250-foot level the normal width of the shoot was 3 feet, but that south of the shaft, at the intersection of two fissures, it widened to 30 feet, the outer portion consisting of rich copper ore and the interior mass, 20 feet wide, of almost pure barite. The ore contained, according to these authors, a little argentiferous galena, though copper largely predominated. Oxidation was complete down to a depth of 100 feet.

VICTOR MINE.

South of the Northern Spy shaft the Godiva channel turns distinctly south-southwestward and continues as more or less interrupted veins down into the North Star property. Little work has been done in this part of the district since about 1900.

The Carisa copper shoot extended with a southwest pitch into the northern part of the Victor Consolidated property but did not continue much below the 700-foot level.

The property of the Victor Consolidated Mining Co. consists of three narrow claims, the Boss Tweed, Victor, and Red Rose, extending side by side along the general course of the veins. The Victor shaft (altitude 7,203 feet), formerly known as the Red Rose shaft, is on the Red Rose claim and is 800 feet deep.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 753.

The Victor tunnel (altitude 6,999 feet) connects with the shaft. Near by is the Boss Tweed shaft, 200 feet deep, having an altitude at the collar of 7,104 feet.

The country rock is metamorphosed limestone of the Bluebell dolomite and the Opohonga limestone, the bedding of which is obliterated. The principal fractures strike N. 35° E.; another system trends north. The ore follows these fissures, extending perhaps 50 feet on a northeast fissure, then 10 feet on a northerly one, then returning to a northeast fissure, and so going step by step to the north-northeast.

The 300-foot level of the Victor was driven on a fissure that is ore bearing in places, to connect with the Carisa workings, on the north, where the largest ore body of the mine was encountered, partly on Victor and partly on Carisa ground. This body in places was 40 to 50 feet wide. A little work was done on the five levels below the 300-foot level, and small bodies of arsenical copper ore were mined. On the lower levels the vein was from 6 inches to 5 feet wide.

At the tunnel level on the Boss Tweed the ore body dips 85° E. At 27 feet below this level it assumes a vertical attitude, which continues 50 feet, below which it dips 85° W. This ore body contains three shoots of rich ore, all of which pitch north at a low angle. The principal minerals are quartz, barite, enargite, tetrahedrite, bismuthite, and galena. The ore contains silver and gold, but copper is the most valuable constituent. Barite occurs locally in great masses, several feet thick. The ores in the tunnel are completely oxidized, but 100 feet below the tunnel level they are but slightly altered. Bismuth is found as a yellow carbonate yielding as much as 42 per cent of bismuth.

Apparently no deep exploration has been undertaken in this mine.

NORTH STAR MINE.

The workings of the North Star mine lie southwest of the Red Rose mine, and the ore bodies along this part of the vein may in general be considered as the most southerly extension of the Godiva channel, reaching within 500 feet of the limestone-monzonite contact.

The mine has been closed since 1900, and the workings were not accessible in 1911.

The shaft is in a branch of Dragon Canyon half a mile east of Diamond Pass and a quarter of a mile north of the Dragon iron mine, at an altitude of 6,920 feet (6,938 according to the Iron Blossom surveys). A 900-foot tunnel (altitude of portal 6,745 feet) opens the mine from the gulch to the east of it. Six levels are turned, and the workings extend 500 feet north-northeasterly and 700 feet south-southwesterly from the shaft. On the 300-foot level a long crosscut has been driven east under the Dragon veins, and the drifts extend far north and south. On the 600-foot level much prospecting has also been undertaken and long crosscuts run east and west.

The deposit is contained in contact-metamorphosed limestone of the Opohonga and Ajax formations, the contact between the two being close to the shaft. The crystalline limestone contains "much quartz, garnet, and wollastonite," according to Tower and Smith.[1] The limestone is intersected by fissures; the principal ones extend north and N. 25° E., but there are also many easterly cross fissures.

The tunnel intersects the main contact of monzonite and limestone not far from its portal, and according to M. L. Crandall, jr., a porphyry dike 100 feet wide is intersected 400 feet west of the shaft.

On the surface an ore-bearing fissure has been traced for 1,500 feet, beginning at the gulch above the shaft, continuing south to the crest of the ridge, and thence trending southwest toward the monzonite contact. This fissure is said to be vertical. No ore bodies of value have been found on it where intersected by the 300 and 400 foot levels.

The principal ore bodies extend just east of the shaft for 1,000 feet more or less continuously and apparently follow steep north-northeasterly fissures with many local offsets on easterly breaks. The ore bodies were irregular, as usual, varying in width from a mere seam up to 30 feet; the greatest thickness usually appeared at the intersection of several fissures. The ore bodies stoped do not seem to have extended far below the 300-foot level, nor more than 500 feet south-southwest and north-northeast of the shaft.

The ore contained[1] quartz, barite, galena, cerusite, iron oxide, and enargite and its oxidation products; it also contained silver and

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 756.

unusually large quantities of gold—in fact, more than any other mine of the district.

The lower levels are said to show a greater amount of lead and silver and less barite than the upper levels. The gold is said to be clearly associated with the fine-grained barite; coarsely crystalline masses of barite occur in the upper workings. The shoots are said to dip west and pitch north. Of these, three were distinctly gold bearing and one carried lead and silver. The copper was found at the south end of the vein.

The total production from this small mine is said to have been $700,000, of which 60 per cent was in gold and the rest in silver, lead, and copper. This figure represents net value—that is, gross value less railroad and smelter charges.

GODIVA ORE ZONE SOUTH OF NORTH STAR MINE.

The Godiva and Iron Blossom ore zones gradually converge near the monzonite contact, where they are a few hundred feet apart. The Godiva channel has not been traced to the contact, nor is its continuation found in the monzonite, though this rock contains several small, undeveloped veins which might be considered to belong to this system of fissures.

MINES OF THE IRON BLOSSOM ORE ZONE.

PROPERTY OF BECK TUNNEL CONSOLIDATED MINING CO.

Location and developments.—The property of the Beck Tunnel Consolidated Mining Co. covers the north end of the Iron Blossom ore zone and consists of several claims on the steep eastern slope of Godiva Mountain. It is controlled by the Knight interests. The north end of the Eureka Hill Railroad passes through the property. The principal ore body, extending over a horizontal length of 1,000 feet, is now mined out but exploratory work is still being continued. Plates XXXV-XXXVII and figures 36–43, illustrating the occurrence, are based on surveys by M. L. Crandall, jr.

The No. 2 Beck Tunnel shaft is close to the railroad track at an altitude of 7,033 feet (7,039 feet according to the mine surveys) and is 1,140 feet deep. Levels are turned at 180, 300, 400, 900, and 1,100 feet, and the principal ore bodies were found on the 300-foot level. Exploratory crosscuts bave been run east and west on several levels. The other shaft, referred to as No. 1, has an altitude of 7,079 feet and is only 300 feet deep, the principal level being turned at this depth. The old Beck Tunnel enters the side of the hill at an altitude of 6,626 feet, or about 400 feet below No. 2 shaft. The upper slope is explored by the Beck tunnel, which enters at the level of No. 2 shaft and connects with the old Humbug (now Uncle Sam) workings. The La Reine tunnel, in which no large ore bodies have been found, enters the side of the hill between the two shafts and about 220 feet above the railroad track.

Production.—The development and active working of the Beck Tunnel property falls between the years 1905 and 1913. According to figures compiled by V. C. Heikes, of the United States Geological Survey, 43,931 tons of ore was mined during that time, yielding 4,547.37 ounces of gold, 1,191,517 ounces of silver, 1,486 pounds of copper, and 18,741,914 pounds of lead, having a total gross value of $1,809,986, corresponding to about $2 in gold and 27 ounces of silver to the ton and about 21.5 per cent of lead. From 1914 to 1916 inclusive the production has declined. The gold and silver content has remained about the same, however, while that of lead has decreased and that of copper, though small, has increased (from 0.002 to 0.08 per cent).

Geology.—The principal formation exposed is the Pine Canyon limestone, and almost its whole thickness is penetrated by No. 2 shaft, which also at the 900-foot level enters the characteristic carbonaceous shales of the uppermost Gardner dolomite and continues into the underlying beds of that formation. The Humbug formation is exposed above the shaft, but no ore occurs in it. The shaft is almost exactly in the vertical axis of the main syncline of the district, the dips being gentle on both sides but becoming higher than 30° in the western part of the property.

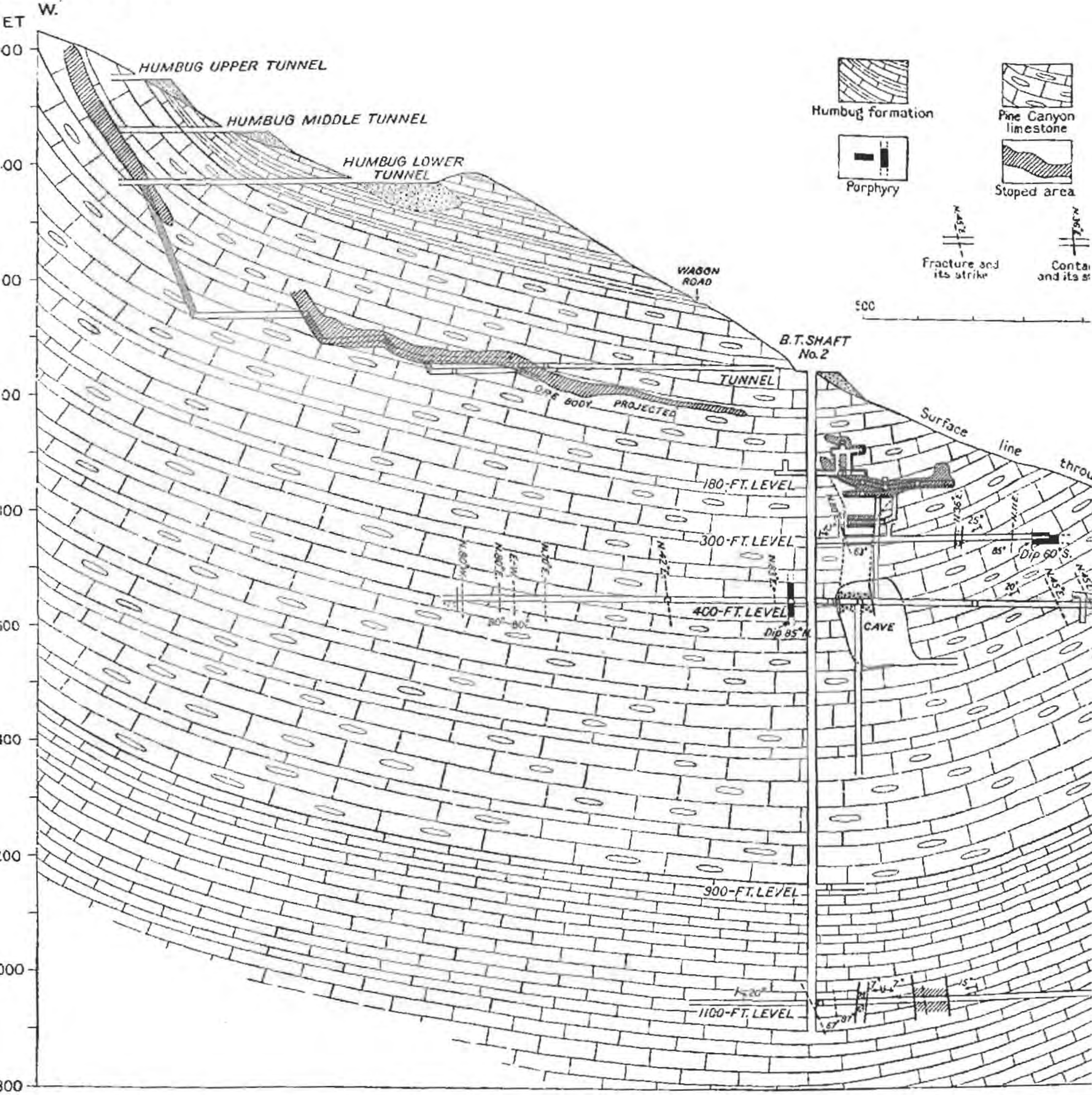
Two narrow dikes of soft, pyritic igneous rock, probably monzonite porphyry, were noted on the 300 and 400 foot levels.

In the vicinity of No. 2 shaft the limestone is intersected by many fractures trending east or N. 60° E. They are seen in the workings of the

PLAN OF ORE BODIES ALONG THE FOURTH ORE ZONE FROM BECK TUNNEL TO IRON BLOSSOM No. 1

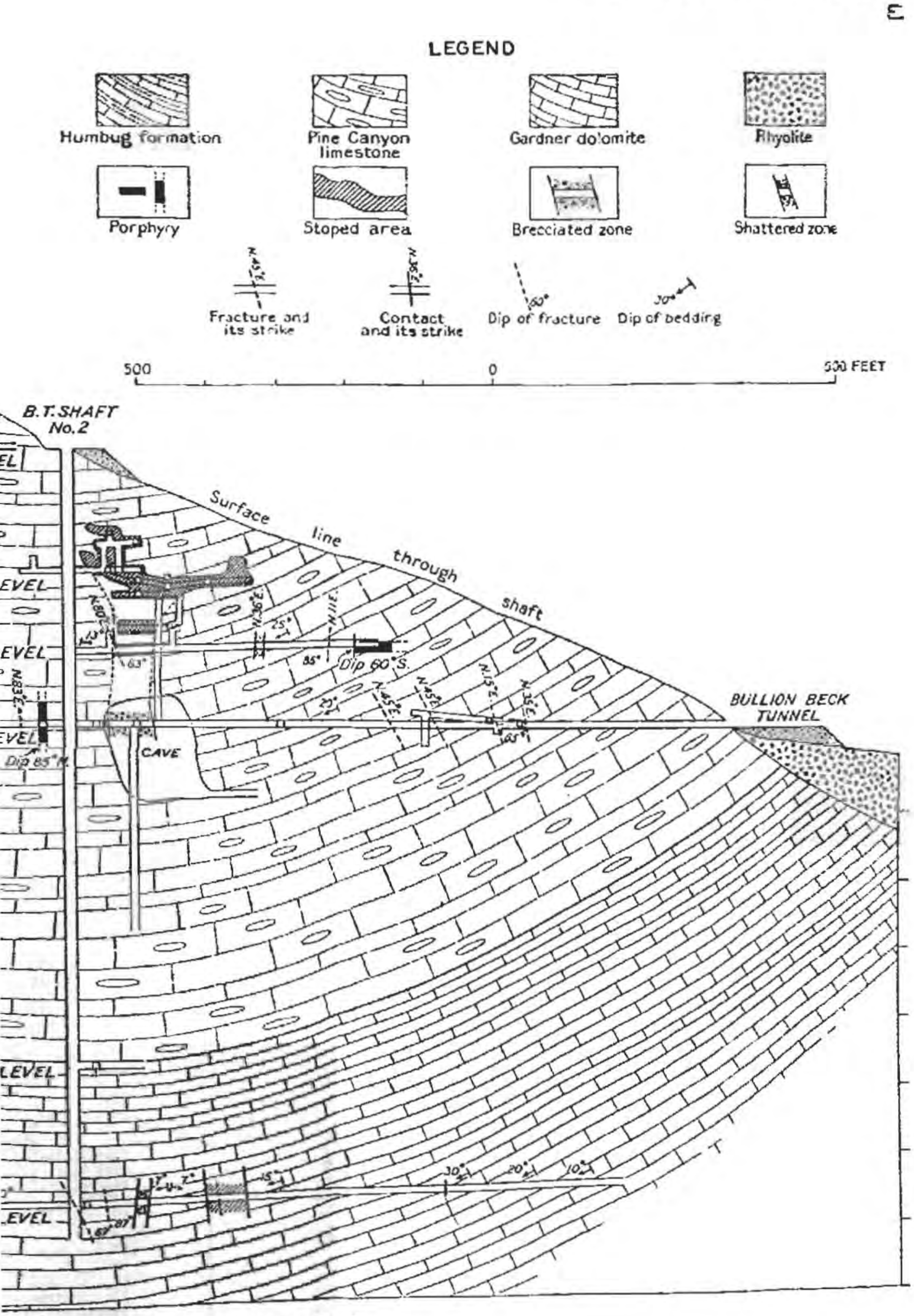
LONGITUDINAL SECTION ALONG THE FOURTH ORE ZONE FROM BECK TUNNEL TO IRON BLOSSOM No. 1

500 0 500 1,000 FEET



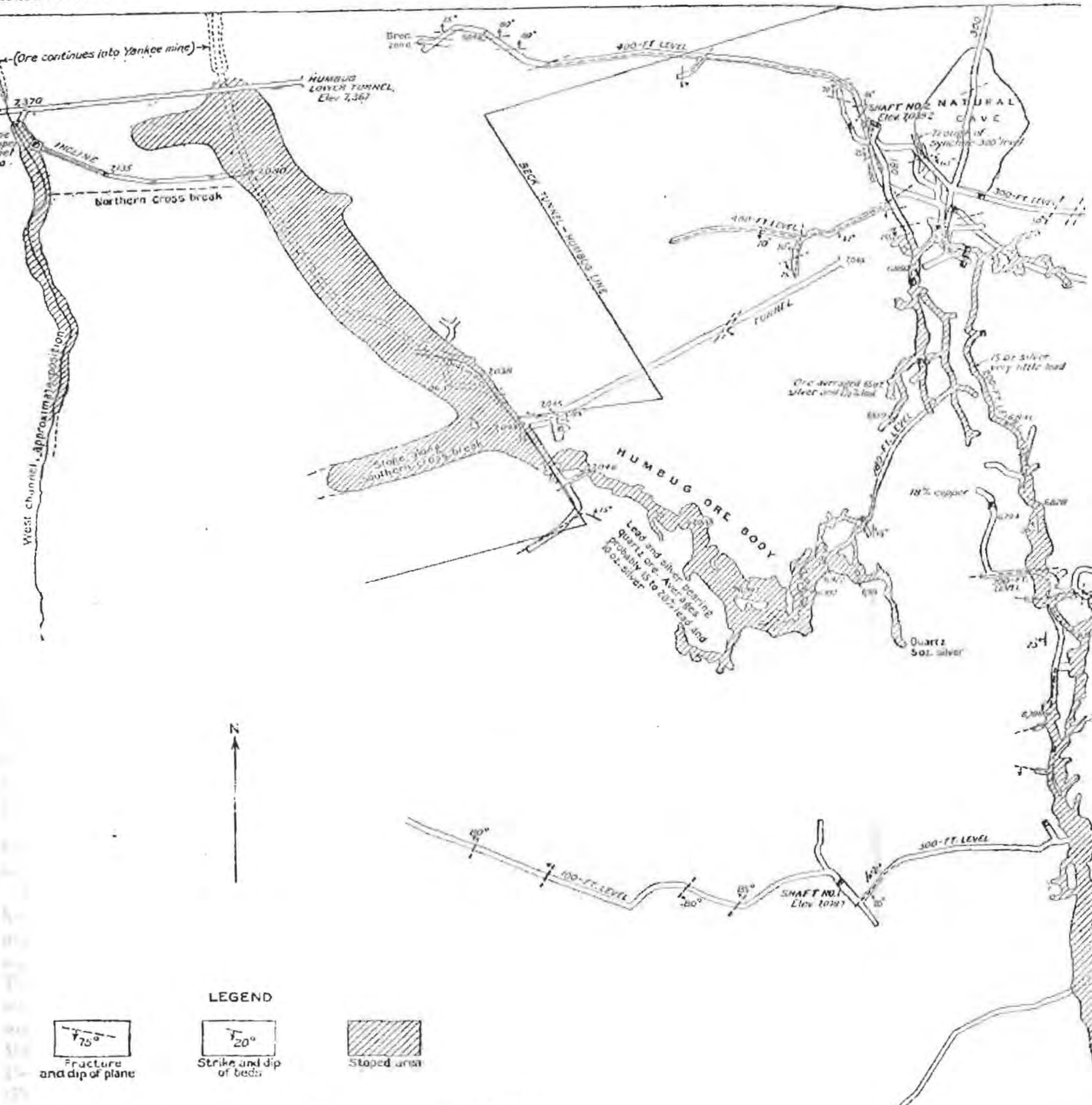
EAST-WEST CROSS SECTION THROUGH BECK TUNNEL SHAFT NO. 2.

Surveys and ore bodies by M. L. Crandall, jr.; geology by Waldemar Lindgren and G. F. Loughlin.



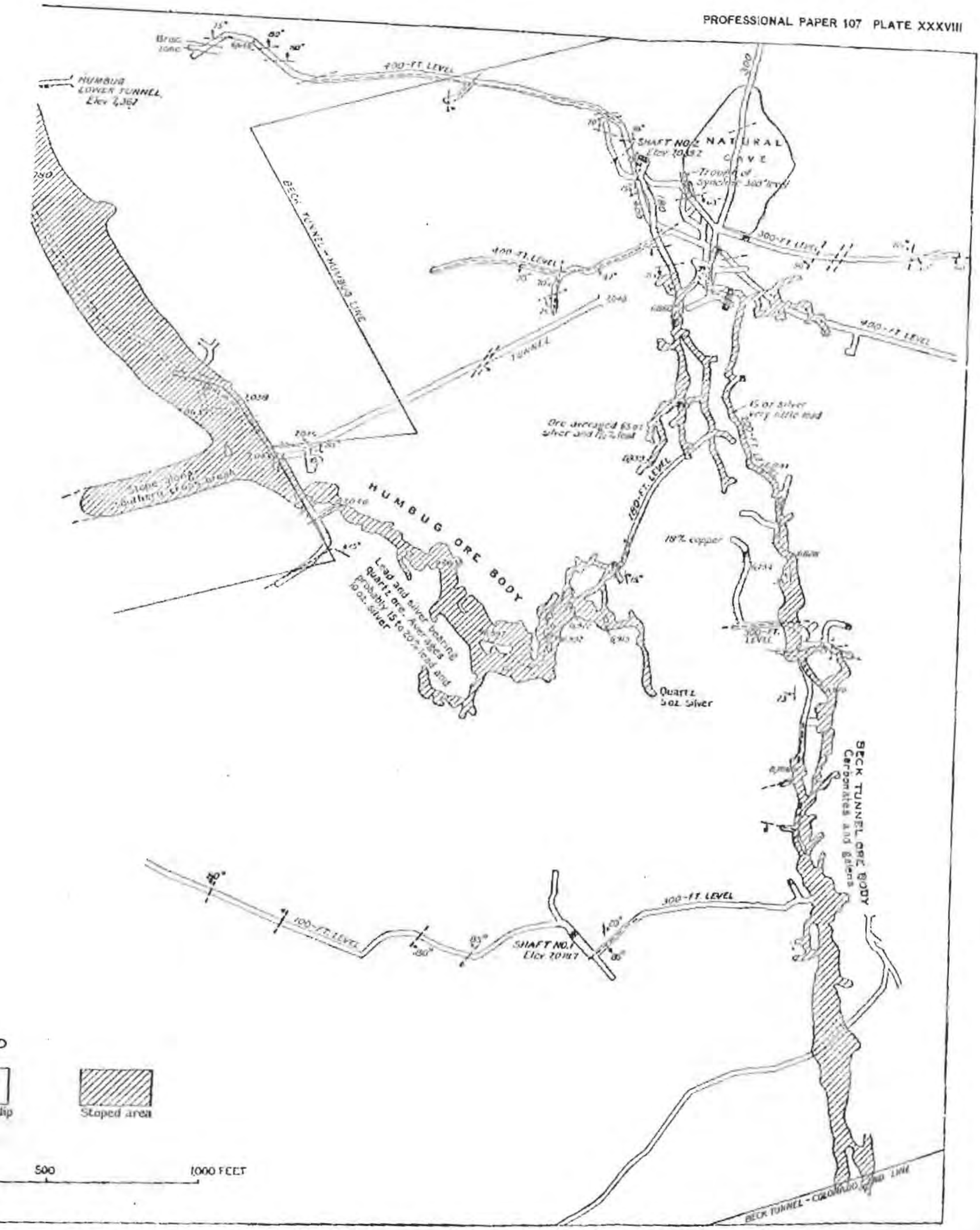
…UGH BECK TUNNEL SHAFT NO. 2.

…eology by Waldemar Lindgren and G. F. Loughlin.



PLAN OF ORE BODIES NEAR BECK TUNNEL SHAFT NO. 2 AND THE HUMBUG TUNNEL.

Surveys by M. L. Crandall, jr.



OF ORE BODIES NEAR BECK TUNNEL SHAFT NO. 2 AND THE HUMBUG TUNNEL.

Surveys by M. L. Crandall, jr.

mine within 100 feet north and south of No. 2 shaft, in the workings of the upper tunnel, and in the La Reine tunnel. The cross breaks trending N. 70°–80° E. are indicated on the geologic map (Pl. IV, in pocket). There is a visible horizontal throw of 25 to 75 feet along the fault zone passing close by the Humbug (Uncle Sam) tunnels; some dislocation has probably also taken place along the other fractures just mentioned, but the amount is not easily determined, owing to the uniform character of the rock exposed. This fault zone has had an important influence on the course of the ore-bearing solutions.

There are several fractures trending north, or N. 20° E., but none of them seem to be very strongly marked. The ore bodies south of the shaft follow a northerly fracture, but north of the fault zone, near No. 2 shaft, this fracture is not prominent.

A large natural cave was found on the 400-foot level just east of the shaft; it is 100 feet wide, 200 feet long, and in places 150 feet high.

Ore bodies.—The main shoot lies almost horizontal, following the bedding, and extends northward. It was first found by a crosscut east from No. 1 shaft on the 300-foot level. This shoot has been mined almost continuously from a point 150 feet south of the shaft to the boundary line of the Colorado Mining Co.'s property. It lies on the whole 150 to 300 feet below the collar of No. 2 shaft (Pl. XXXVI) and is from 10 to 40 feet high and 20 to 70 feet wide from east to west. The form is thus that of a horizontal pipe, which was followed in this property for 1,300 feet from north to south. It lies conformable to the bedding of a coarse-grained member of the upper part of the Pine Canyon formation 200 feet below the Humbug formation and parallel to the horizontal axis of the syncline, with which it almost coincides. Cross sections of the shoot are given in Plate XXXVII and figure 36, and the horizontal projection in Plate XXXV. The shoot is really considerably larger than the dimensions above given for masses of low-grade siliceous ore and silicified limestone adjoin the stopes in most places. A short distance south of No. 2 shaft the shoot meets the zone of easterly fractures and ceases rather abruptly, the mineralization probably continuing on these cross fractures to the west and connecting with the flat shoots near the Humbug (Uncle Sam) tunnels. (See Pl. XXXVIII.) Little exploration work seems to have been undertaken to ascertain if the ore does not also continue on this zone of cross fractures to the east.

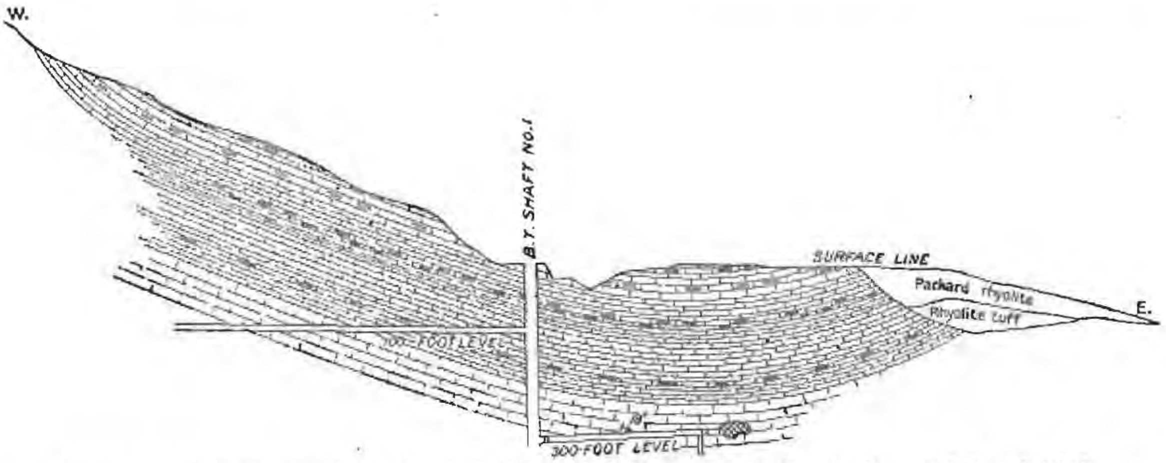


FIGURE 36.—Cross section along line A-A', Plate XXXVI, through Beck Tunnel shaft No. 1, showing ore body (cross hatched).

Near No. 2 shaft the shoot is considerably higher than elsewhere and extends, including the silicified masses, from a point 100 feet below the shaft collar to the cave, or 400 feet below the collar. Whether the silicified zone below the 1,000-foot level has any connection with the upper stopes can not be decided, owing to the lack of intervening developments.

There are some indications that this horizontal shoot follows a vertical northerly fissure, but they are not strongly marked.

The beginning of the shoot is seen on the 180-foot level; for 100 feet from the shaft the drift is in coarse limestone without plain bedding, and beyond this is a bunch of cellular, low-grade siliceous ore, some of which has been stoped; there is also some ore on the 125 and 145 foot sublevels and a little on the 300-foot level immediately below the stope on the 180-foot level. Farther south the ore on the 180-foot level develops in flat stopes, which on the west gradually turn up to easterly dips of 20°–25°. About 300 feet south of the shaft a winze goes down in solid limestone to the 260-foot level, and the explorations on the 400-foot level seem to show that there is no ore in this vicinity below the main horizontal shoot. Near No. 1 shaft the ore pipe drops gradually to an altitude of 7,780 feet, but within a short distance it rises to the same level, 7,840 feet, which it had in the northern part of the shoot. In the crosscut from No. 1 shaft to the ore coarse limestone alternates with fine-grained beds.

The ore.—The ore mined in the main shoot consists of galena and lead carbonate in a siliceous gangue, with some limonite, manganese oxide, more or less barite, and films of horn silver. An average of the ore mined shows $2 in gold to the ton, or much less than farther south on the same ore zone, 27 ounces of silver to the ton, and 21.5 per cent of lead; there is practically no copper. Some of the ore contains as much as $4 in gold, and 40 or 50 ounces of silver to the ton and 40 to 50 per cent of lead. Many local bunches of silver chloride were encountered. The low-grade siliceous ore, of which much remains in the mine and which accompanies and surrounds the heavy lead ores, carries 4 to 5 per cent of lead and perhaps 10 ounces of silver and $1 or $2 in gold to the ton.

In general the silicified limestone is fine grained, more or less brecciated, and corroded. A later white drusy quartz with very small crystals fills the cavities, and this later quartz seems to be associated with most of the ore minerals. Much of it is honeycombed and cellular, indicating a removal of some constituent. Near the outside of the ore bodies there are greater or less amounts of oxidized iron and manganese minerals, and silicified limestone begins along the bedding planes. Very little galena was seen in the old stopes.

In the tunnel connecting with the Uncle Sam (Humbug) workings the ore occurs in the bedding planes of the Pine Canyon limestone, 500 feet west of the main shoot but at about the same horizon, and also on the N. 60° E. cross breaks, of which many are found in this vicinity. There has been little silicification along these breaks, but they show much calcite and dolomite. In the ore along the beds coarse galena predominates, accompanied by calcite and some loose and cellular silicified material. Ore from this place was shipped in 1911.

PROPERTY OF COLORADO MINING CO.

Location and development.—The property of the Colorado Mining Co. adjoins that of the Beck Tunnel Consolidated Co. on the south and lies on the steep northeast slope of Sioux Peak. It contains the continuation of the Iron Blossom ore shoot, mined for 1,300 feet in the Beck Tunnel property, and the ore has been followed practically continuously through the property for 2,500 feet. The two shafts are close to the railroad spur, No. 2 has an altitude at the collar of 7,102 feet (7,110 feet by the mine survey), and No. 1 of 7,137 feet (mine survey). No. 2 shaft, the more northerly, is 300 feet deep; No. 1 shaft 500 feet deep. The mining operations have consisted chiefly in following the well-defined ore channel, which here lies a little deeper than in the Beck Tunnel property, averaging 300 feet below the surface. The linear developments in the mine aggregate 14,000 feet. Crosscutting east and west has been done from No. 1 shaft on the 250 and 500 foot levels without disclosing any ore, but no deeper exploration has been attempted—a fact which seems singular, considering the great production of the company.

Production.—The Colorado Mining Co. produced 108,939 tons of ore between 1907 and 1913, containing 20,676.76 ounces of gold ($427,424), 4,889,832 ounces of silver ($2,708,976), 15,665 pounds of copper, and 48,171,127 pounds of lead, the whole having a gross value of $5,275,085. The ore thus averaged about $4 in gold, and 45 ounces of silver to the ton, 0.14 per cent of copper, and 45 per cent of lead. The production has declined considerably since 1913, although 1916 showed

a marked increase over the two preceding years. The content of gold, silver, copper, and lead during the three years 1914–1916 has decreased, but zinc, first produced in 1914, has attained considerable importance.

Geology.—The geologic conditions are very similar to those in the Beck Tunnel property. Both shafts are sunk in the Humbug formation but enter the Pine Canyon limestone at a depth of 60 to 80 feet, and the ore horizon lies about 160 feet below the contact or at an altitude about 100 feet higher than near No. 2 shaft in the Beck Tunnel property. The ore continues to follow the almost horizontal axis of the syncline, and the dips are generally less than 10° E. or W. A small area of rhyolite rests on the limestone below the No. 2 Colorado shaft. The last paragraph its bottom attains an altitude of 6,900 feet. Near the Sioux line the ore shoot again sinks to the 6,850-foot level; whether or not there is a dislocation at this place can not be definitely stated. The stopes range in width from 20 to 60 feet, and their horizontal outline as seen in Plate XXI indicates the appearance of the ore body in cross section. The height of the stopes increases toward the south. Near No. 2 shaft few of them are over 20 feet high, but in places the Horn Silver and Spanish Fork stopes reach 60 feet; near the Sioux line, however, they again become lower.

The ore.—The ore in the Colorado mine contains on the average much more lead and silver than that of the Beck Tunnel property, but its general character is very similar. It contains

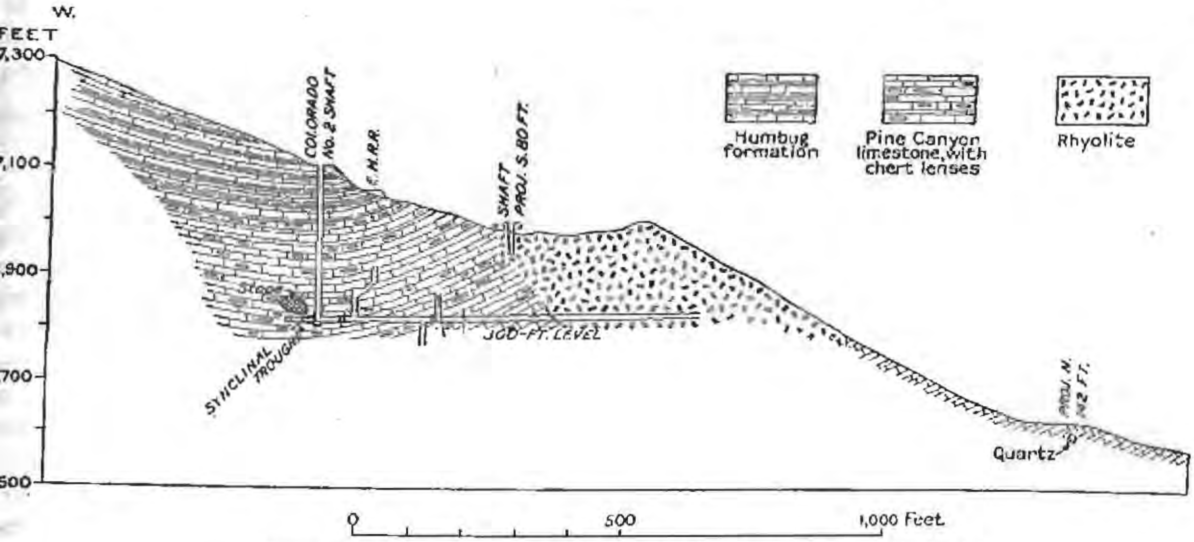


FIGURE 37.—Cross section through Colorado shaft No. 2 along line B-B', Plate XXXVI.

ortherly fissures that are followed by the ore ody are a little more prominent than in the Beck Tunnel property. There are several ross breaks of little importance, but 400 feet orth of No. 1 shaft a brecciated zone crosses the re body, and along this zone the ore body appears to have been downfaulted on the north side. large cave 200 feet long and 30 feet high occupies the ore horizon below No. 1 shaft, but its evelopment is a comparatively late feature.

Ore body.—The ore zone continues as in the eck Tunnel property, forming a horizontal pe in the upper part of the Pine Canyon nestone and trending almost exactly north r 2,500 feet across the Colorado property. s northerly part lies at an altitude of 6,850 et, but south of the break referred to in the

much carbonate, in part massive, in part sandy, and some residual masses of galena. A little copper begins to appear in the ore. There is some zinc blende in the galena, though most of it is converted to calamine and smithsonite. A small pocket of oxidized ore averaging 15 to 30 per cent zinc was opened in 1915. The ore is highly siliceous in places—for instance, in the Horn Silver stopes—and here the percentage of lead may be very low.

The published annual report of the company for 1911 gives the following details: Ore mined, 19,210 dry tons; average gold per ton, 0.17 ounce; average silver per ton, 31.87 ounces; lead, 10.18 per cent; gross value per ton, \$25; smelting and transportation per ton, \$9.27; operating costs per ton, \$3.79.

Dark silicified limestone surrounds the ore shoot; its greatest extent is in a horizontal direction along the bedding planes; in places it begins 30 to 50 feet away from the ore pipe.

The large cave contained much lead carbonate and kidneys of galena and was evidently caused by the solution of part of the limestone surrounding the ore.

PROPERTY OF SIOUX CONSOLIDATED MINING CO.

Location and development.—The Iron Blossom ore channel continues from the Colorado mine into the property of the Sioux Consolidated Mining Co. and has been mined without interruption from north to south. The total length in this property is only 650 feet.

The Sioux shaft has an altitude of 7,180 feet at the collar and is about 500 feet deep. Developments are chiefly on the 300-foot level, though a crosscut 1,000 feet long has been extended west on the 200-foot level without finding new ore. There are shorter crosscuts eastward on the 300, 450, and 500 foot levels. The mine was worked principally between 1908 and 1912.

Geology and ore bodies.—The geologic features are very similar to those of the Colorado mine. The shaft is sunk in the Humbug formation but remains in it only for about 120 to 150 feet, and the bottom of the ore channel lies about 200 feet below the contact of the Humbug formation and the Pine Canyon limestone. The beds lie nearly horizontal. The bottom of the ore channel or pipe has an altitude of 6,850 feet; the south end is a little lower, or at about 6,830 feet.

The ore body averaged about the same as in the Colorado mine but was in many places 100 to 150 feet wide; its height was about 20 feet but increased to 40 feet near the southern boundary. The tonnage produced was large, though not as large as that of the Colorado, and the ore averaged $3.50 in gold and 35 ounces of silver to the ton, 0.26 per cent of copper, and 35 per cent of lead.

Where inspected, at the north end of the property, the ore was flat, 30 feet high, and contained a great deal of galena and carbonate and sulphate ore. An excellent opportunity was afforded here for studying the processes of oxidation of galena (p. 174). Both coarse and fine grained (steel) galena occurred at the west edge of the lead shoot, and at this place there are large masses of silicified limestone. The east side of the channel is 40 feet lower than the west side, indicating the slight easterly dip of the beds. In this silicified limestone are scattered bunches of white crusted quartz, but the bulk of the rock is fine grained or cherty and dark gray. It contains a little silver but is not considered even low-grade ore.

The ore is so similar to that of the Beck Tunnel and Colorado mines that no description is necessary. In the southern part of the Sioux ground the ore becomes very siliceous, with great amounts of white loose sugary quartz, evidently produced by leaching and crushing of cellular and honeycombed ore. Rich horn silver ore occurs in places, also much breccia of dark silicified limestone cemented by cellular quartz, each division coated with late quartz crusts of small crystals.

PROPERTY OF IRON BLOSSOM CONSOLIDATED MINING CO.

Location and development.—The property of the Iron Blossom Consolidated Mining Co. extends for 3,200 feet along the Iron Blossom ore zone, on the steep easterly slope of Mammoth Peak. Ore has been mined almost continuously through the ground from the Sioux line on the north to the end line of the Governor claim on the south. The direction of the ore zone is N. 20°–30° E.

Two shafts open the property. No. 3 shaft is in the northern part of the area mined and has an altitude at the collar of 7,179 feet; No. 1 shaft, 2,300 feet farther south-southwest, has an altitude of 7,275 feet (7,293 according to the mine surveys). No. 2 shaft is shallow and of no importance.

No. 3 shaft is vertical and is 590 feet deep, and a winze from that level extends to the 680-foot level. The ore bodies lie mainly on the 380 and 480 foot levels, along which the property is opened through its whole length. Several crosscuts explore the country rock on the east for a few hundred feet. No. 1 shaft is also vertical and reaches a depth of 1,900 feet. The principal developments are on the 500 and 600 foot levels. The 600-foot level continues south through the Governor claim, and a long drift south on the 1,900-foot level parallels the Governor side line but lies within the Iron Blossom property. Crosscuts from 500 to 800 feet long

tend west on the 200 and 500 foot levels and st on the 700-foot level. The developments gregate about 8 miles.

Water stands on level 19, though this is obably not the true water level but only a cal accumulation.

Production.—The Iron Blossom mine entered ranks of the producers in 1908 and has ce continued to be one of the heaviest ship-rs of ore in the district. The total produc-n, from 1908 to 1916, inclusive, amounted to ,457 tons of ore, which yielded 66,174 nces of gold ($1,367,817), 10,689,487 ounces silver ($6,055,203), 2,804,689 pounds of cop-, 50,284,075 pounds of lead, and 124,114 nds of zinc, making in all a gross value of ,208,434.

he ores comprise medium-grade lead ore h gold and silver and siliceous gold-silver with little or no lead. The ore shipped lded an average of $4.45 in gold and 32 ces of silver to the ton, 7.5 per cent of l, and 0.25 per cent of copper.

n 1914 about 50,000 tons of ore was shipped a great tonnage of second-class ore remains the mine. Dividends of $2,170,000 have n paid by the company up to October 26, 1.

eology near No. 3 shaft.—The principal de-t enters the Iron Blossom ground from the ux under conditions entirely similar to those he Sioux mine. No. 3 shaft is sunk wholly he Pine Canyon limestone, the collar being a few feet below its top. The ore body about 300 feet below the contact of the Canyon and Humbug formations; and nally the bottom of the shaft, 590 feet be-the collar, should be in the same formation, otal thickness being about 1,000 feet. The near the ore body are about 20° E.

ss than 200 feet south of the shaft the s enter the great Sioux fault zone, here t 300 feet wide. In this disturbed zone inds of faults abound, northerly as well as rly; the dips increase locally to 40° and 60°, and the carbonaceous beds at the top e Gardner dolomite appear in small fault ks in the fault zone on the 300-foot level, in the crosscut to the southeast of the oot level, indicating a vertical maximum v of about 800 feet in this part of the fault . The faulting also finds expression in the ralization by extensive silicification and in the disposition of the ore bodies, although these are later than at least the principal fault movements.

South of the fault zone the ore body continues in a straight line for a long distance and assumes more clearly the outline and characteristics of a replacement vein. The horizon of the limestone is not definitely determined. It is the Bluebell dolomite on the surface, which would indicate a total vertical displacement of 1,500 feet across the fault zone. The end of the 380-foot level in 1911, 1,200 feet south-southwest of No. 3 shaft, was still in greatly disturbed limestone with several northerly fissures.

Several dikes of a greatly altered porphyry appear in the workings of No. 3 Iron Blossom. On the 380-foot level one dike about 10 feet wide lies in the disturbed zone and has a strike parallel to that of the main faulting, or N. 70° E. On the 480-foot level this dike is not found, but a faulted block of porphyry lies along the main drift 100 feet south. The conditions here suggest post-intrusive faulting. On the same level a dike has been struck in a crosscut 550 feet east-southeast of the shaft and another in a crosscut 1,200 feet south-southwest of the shaft. These intrusives are probably monzonite porphyries but are not easily recognized, as they are extensively replaced by sericite and calcite and contain small crystals of pyrite. They do not contain ore, though in places iron-stained siliceous low-grade ore lies along the contact of dike and limestone. No dikes show on the 580-foot level.

A large cave was found in the southern part of the No. 3 workings. It is 250 feet long, 40 to 60 feet wide, and 10 to 20 feet high. It lies about parallel to the ore body and just above it. Its outline in longitudinal section (Pl. XXXVI, in pocket, resembles the section of a bowl. At the bottom of the cave is some carbonate ore showing copper stain, and this material is in part stoped. The walls of this cave were coated with snow-white botryoidal masses of calcite and beautiful arborescent growths of the same mineral. In places the calcite was covered by needles of aragonite. This secondary calcite contains no ore minerals. There is little doubt that the cave has been produced by the oxidation and shrinkage of the ore body below it.

Ore bodies and ore in No. 3 Iron Blossom.—From the Sioux mine the ore body continues for 250 feet horizontally in the Iron Blossom, but its width is as much as 170 feet; it is from 20 to 60 feet thick, growing thicker toward the southern end. The ore (Pls. XXXV and XXXVI, figs. 38 and 39) lies on the western limb of the syncline, and its extension is parallel to the beds so that the dip of the body is 13°–20° E. The south end is not only thicker but also has sagged 50 to 70 feet. This ore body is in general surrounded by the coarse limestone, and comparatively little silicified material is seen outside of it.

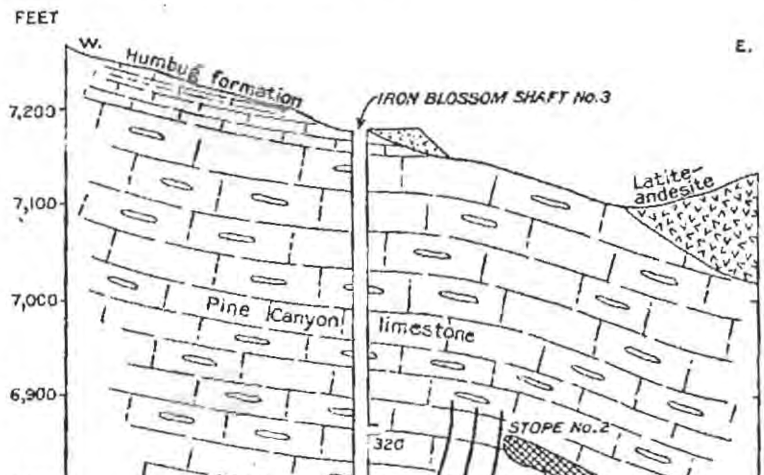


FIGURE 38.—Cross section through Iron Blossom shaft No. 3 along line C–C', Plate XXXVI.

The ore in this shoot—practically the end of the horizontal pipe in Pine Canyon limestone—was on the whole of siliceous character but contained in places much lead carbonate with residual kernels of galena. The dark gray cherty silicified limestone is extensively brecciated and cemented by loose sugary quartz with druses of small quartz crystals. Much of the ore is of this sugary character and locally contains plates of barite. The ore does not contain much iron or manganese, although it is stained brown in many places. On the whole the carbonate and galena ore lies on top of the siliceous ore. Marked horizontal banded structure is shown in places, carbonate ore alternating with sugary quartz and streaks of more compact quartz. In places there is much horn silver.

This ore body terminates rather sharply 400 feet south of the shaft, and beyond it the drifts enter a wide silicified zone in which there is little ore but a great deal of black silicified and cherty material brecciated by small veins of quartz and barite. On the 380 and 480 foot levels the drifts traverse this siliceous material for 400 or 500 feet; on the 480-foot level 600 feet southeast of the shaft the gray limestone is sharply cut off by what appears to be one of the principal fractures of the Sioux fault, here trending N. 70° E. On the 580-foot level there has been much less silicification.

South of the fault zone the ore lies mainly below the 380-foot level instead of above it. The first mass encountered, 600 feet south-southeast of the shaft, is a transverse body (Pl. XXXV) trending nearly east for 160 feet and extending 50 feet above and 60 feet below the 480-foot level; the stopes then turn and continue for 1,000 feet south-southwest, about 20 to 30 feet wide and increasing in height to 100 or 150 feet above the 480-foot level. They assume more of a vein form, and the vein dips steeply to the west.

In this vicinity two more veins appear, one of little value on the west side and another containing a good body of lead ore (mixed carbonate and galena) on the east side. This "east vein" has indeed been traced a few hundred feet north of the section shown in figure 39 and is of considerable value in Iron Blossom No. 1.

The principal stopes contain sugary quartz, locally with barite plates, bunches of limonite, cerusite, and galena. The lead minerals appear mainly in the upper parts and on the sides of the stopes. There is no dark silicified limestone surrounding the stopes, which are, on the contrary, inclosed by little altered limestone or dolomite. The principal value of the ore is in gold.

There are two main classes of ore in the stopes of Iron Blossom No. 3. The lead ores range from 5 to 15 per cent of lead and 20 to 40

ounces of silver and \$5 to \$6 in gold to the ton. The siliceous ores contain 60 to 80 per cent of silica, 1 per cent of lead, and 20 to 40 ounces of silver and \$5 to \$6 in gold to the ton.

The published report of the company for 1914 gives the tonnage from No. 3 shaft during that year at 24,029 tons, averaging 12.40 per cent of lead, 0.7 per cent of copper, and 31.77 ounces of silver and 0.1495 ounce of gold to the ton.

Geology at Iron Blossom No. 1 shaft.—Although the two parts of the mine opened by No. 1 and No. 2 shafts are now connected, it seems best to describe them separately.

No. 1 shaft is sunk at a point near Sioux Pass and its collar is about 100 feet above that of No. 3. It is in the crystalline and contact-metamorphosed Bluebell dolomite near its contact with monzonite porphyry. In this vicinity there is considerable difficulty in identifying the sedimentary formations. The bedding is indistinct but generally 20°–30° NE. The monzonite porphyry is probably intrusive but shows transitions into rocks that are surely effusive. The shaft begins in a small outcrop of altered rhyolitic rocks, which here, as shown on the map (Pl. IV, in pocket), separate the monzonite porphyry from the dolomite.

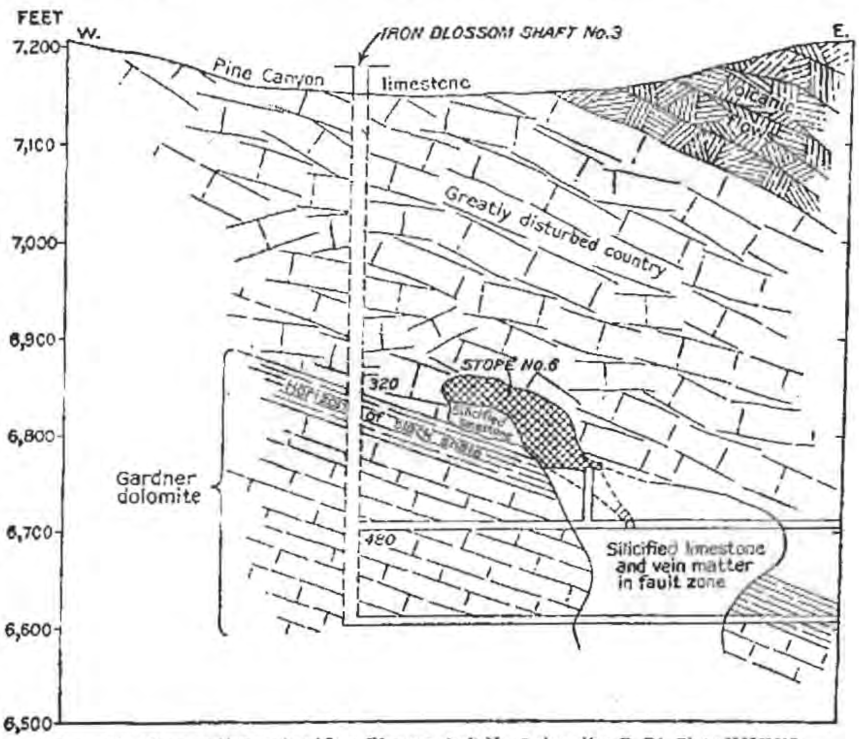


FIGURE 39.—Cross section south of Iron Blossom shaft No. 3 along line D–D′, Plate XXXVI.

An isolated area of monzonite, about 800 by 500 feet, running out into dikes at its south end, is contained in the dolomite north and north-northeast of the shaft; the nearest outcrop of this rock lies 200 feet north of the shaft. The shaft is 1,900 feet deep and in limestone throughout, but the several formations are difficult to identify; the strata show none of the coarse-grained limestone characteristic of the upper Pine Canyon, or of the carbonaceous shale of the upper Gardner. Most of the rock is dolomitic and fine grained. There is not much evidence of contact metamorphism except in the 1,700-foot level, at the south face of which, not far from the station, coarse-grained metamorphic limestone appears. The bedding is flat and the dip east or northeast at gentle angles; well-bedded limestone is shown on levels 5, 6, 7, 8, 11, and 17. The strata of the lower levels belong in part to the Opohonga limestone, which has indeed been definitely identified on level 5 south of stope 4 and also on level 7, 400 feet east of the vein.

Dikes were observed at many places. The tunnel equivalent to level 2 enters in monzonite porphyry, which continues up to the vein near the shaft. The crosscuts 200 to 400 feet west of the shaft on levels 2, 4, 5, and 17 cut several dikes of monzonite porphyry, most of which contain much calcite and scattered small crystals of pyrite. One of these dikes on level 17 extends north for 200 feet and is 8 feet wide. Several of the dikes appear to have been faulted. Along the vein, both north and south of the shaft, a few small dikes of monzonite porphyry have also been observed and generally strike north-northeast. A long crosscut on level 7 encounters monzonite porphyry at the face, 800 feet east of the shaft, which shows that the limestone surface slopes below the porphyry of the surface at an angle

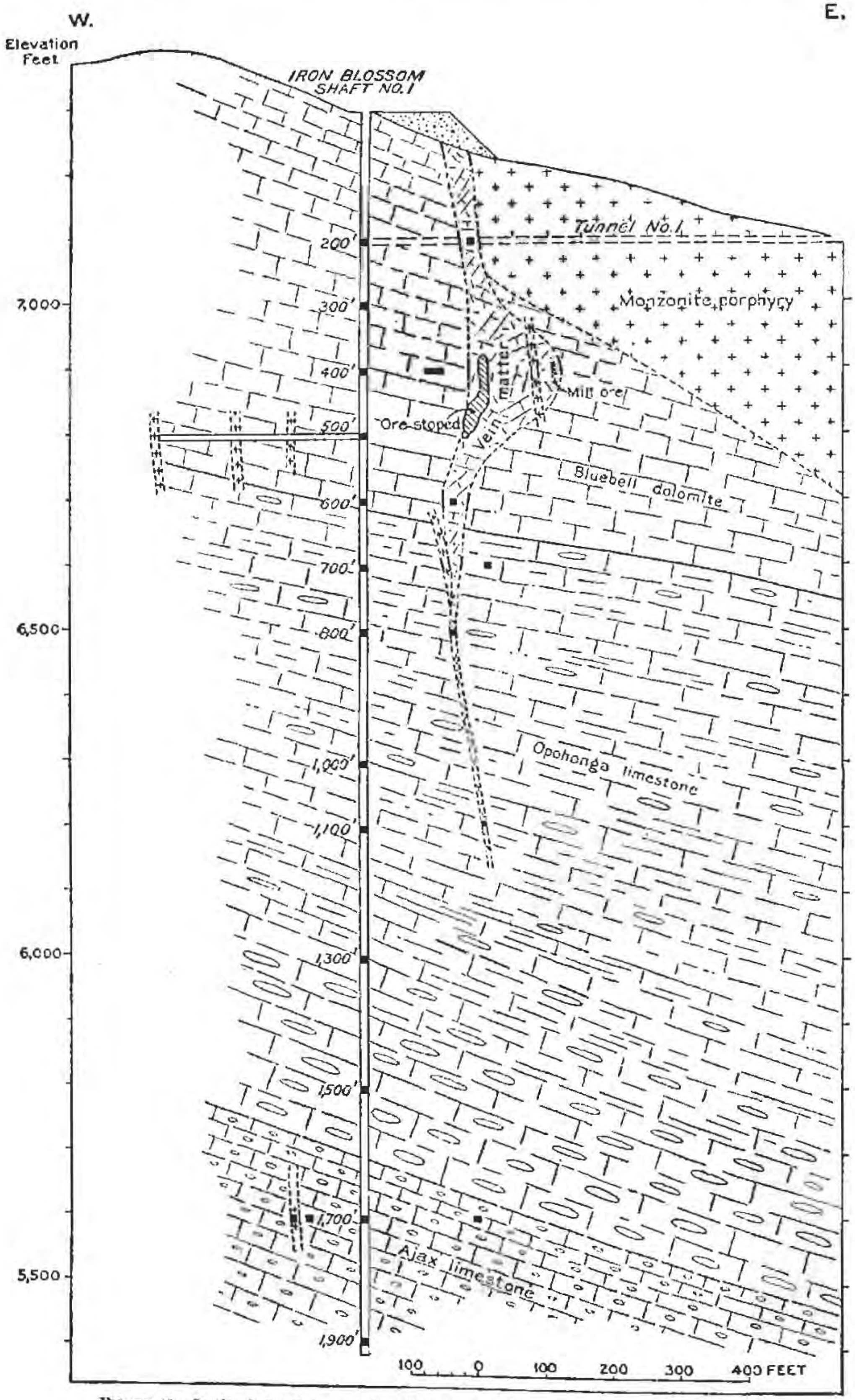


FIGURE 40.—Section S. 56° E. through Iron Blossom shaft No. 1 along line E-E', Plate XXXVI.

that is not steeper than 45°. On levels 2 and 7 the main porphyry contact is vertical along fissures, a fact which probably indicates post-porphyry faulting. The impression gained is that the porphyry is intrusive into the limestone.

Mr. Crandall writes, under date of November, 1914, of an interesting cave recently found in the ore zone on level 5 of the Iron Blossom No. 1. This cave lies in the ore-bearing zone and is 70 feet long, 5 to 10 feet wide, and 3 to 10 feet high. The roof is incrusted with small calcite crystals, some oxidized copper minerals, small stalactites of limonite, and masses of limonite with rhombic cavities (probably casts of gypsum crystals). On top of the loosely compacted material that forms the floor are several large masses of gypsum, both crystallized and massive, with small inclusions of limonite. One mass measuring 5 by 7 by 12 feet is composed largely of long, slender crossing and interlocking prisms of gypsum; some of these crystals are 12 to 17 inches long.

Ore bodies and ore near No. 1 shaft.—In the southern part of the territory opened by No. 3 shaft the horizontal ore pipe assumes gradually the character of a vein. Near No. 1 shaft this becomes more strongly marked, as shown in figure 40. Nevertheless the principal ore bodies lie at about the same level as farther north—that is, on levels 5 and 6. The figure also indicates by dotted lines the outline of the vein matter and silicified limestone. On the lower levels the vein contracts sharply and is not definitely traceable below level 11. Its width ranges from a few feet to 70 or 80 feet. The vein stands nearly vertical or dips a few degrees to the west. The ore is of the same siliceous and cellular character as in No. 3, but contains much more limonite and shows plentiful copper stains.

From the shaft the ore body is reached by easterly crosscuts about 150 feet in length.

The outcrop of the vein does not show on the tuff ridge northeast of Sioux Pass, but silicified and iron-stained croppings appear in a projecting tongue of limestone near the shaft. The vein apparently cuts across the monzonite porphyry but is not clearly shown. South of the shaft it again enters the limestone. On level 2 the vein lies at the vertical contact of limestone and porphyry; it is here 10 feet wide but is obscured by oxidation. It gives small assays in gold and silver. The porphyry is bleached and iron stained.

The principal ore bodies above and below level 5 are 100 to 150 feet high and 10 to 50 feet wide, extending practically continuously throughout the ground. At the south end of

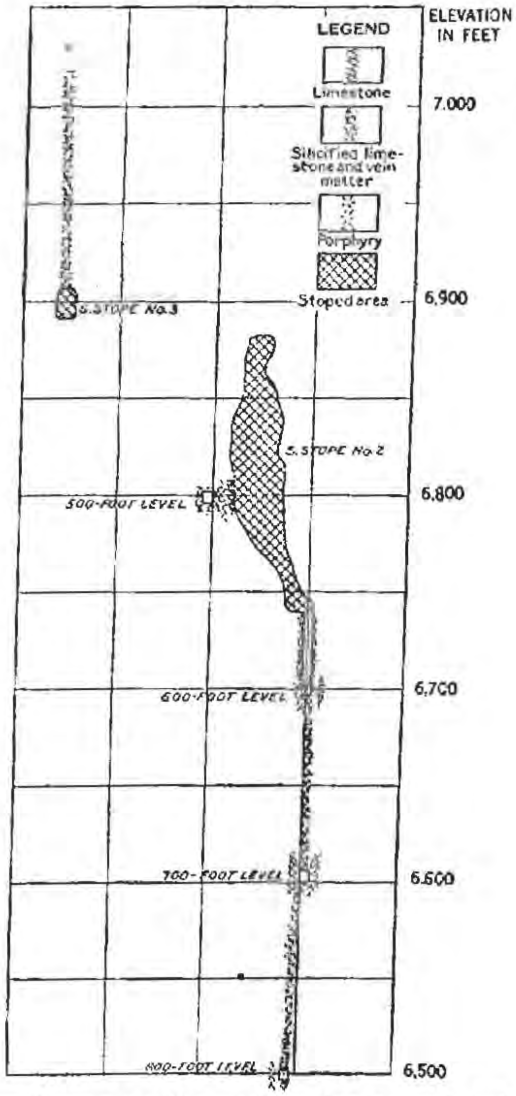


FIGURE 41.—Section S. 58° E. south of Iron Blossom shaft No. 1 along line F-F', Plate XXXVI.

level 5 the vein loses itself in the flat limestone beds. In many places the deposit shows plainly its veinlike character. The walls of limestone are well marked, the vein consists of silicified limestone brecciated and cemented by sugary quartz, and a well-defined lighter streak where filling no doubt has played a part indicates the central fissure.

At the south end of level 6, near the Governor line, are small copper stopes. In places in

this vicinity the vein is only 1 foot wide, and a fine-grained porphyry dike containing pyrite adjoins it.

On level 7 the vein shows at the end of the crosscut from the shaft; it is stained by limonite and malachite.

On level 8, at the crosscut, the vein is only 3 feet wide and consists of iron-stained silicified enargite, and covellite. This ore is said to contain \$2 to \$3 in gold and 9 ounces or more in silver to the ton and 2 to 3 per cent of copper. No larger bodies were found.

On level 11, at the crosscut, the vein is in limestone, is only 1 foot wide, and consists of limonite and quartz with copper stains. Copper ore has been stoped in this level. To the south

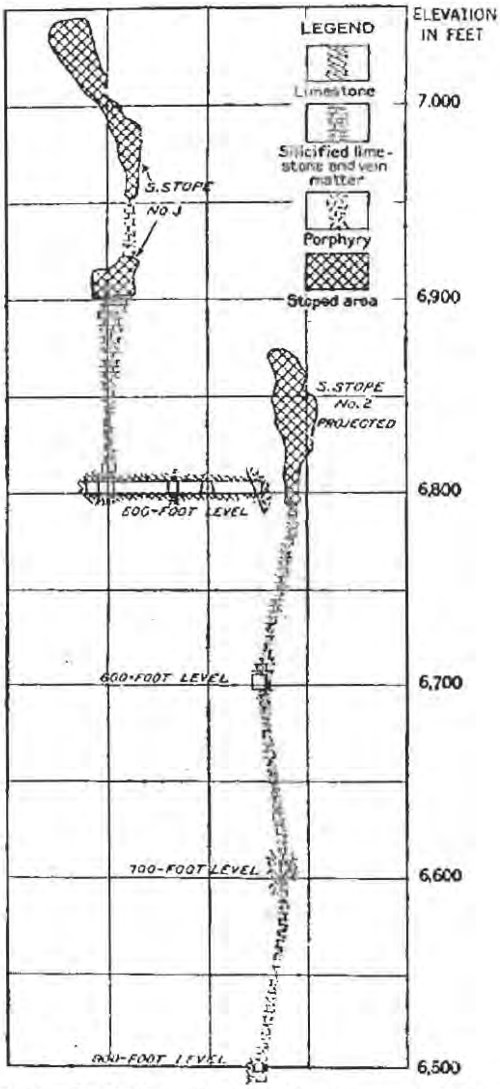


FIGURE 42.—Section S. 58° E. south of Iron Blossom shaft No. 1 along line G-G', Plate XXXVI.

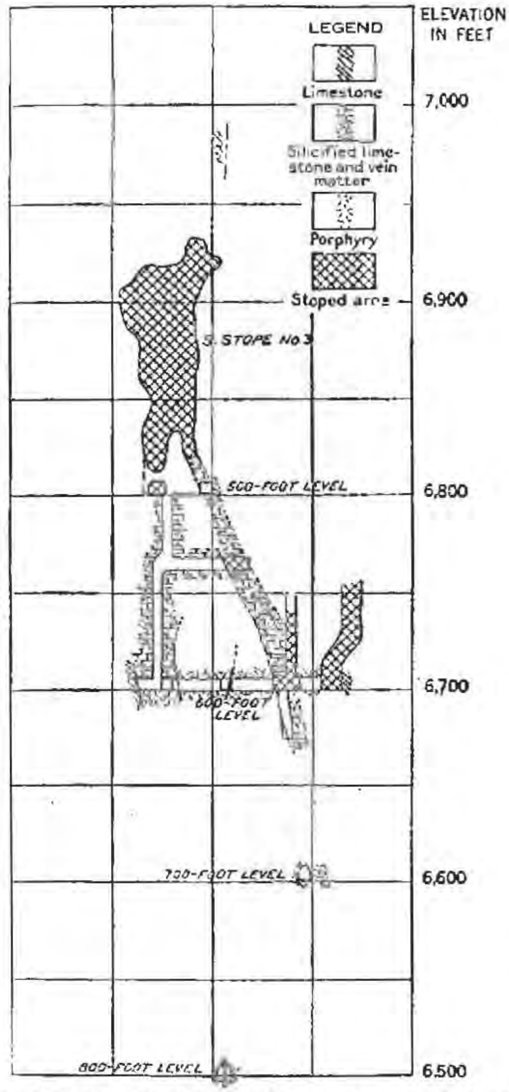


FIGURE 43.—Section S. 58° E. south of Iron Blossom shaft No. 1 along line H-H', Plate XXXVI.

limestone with normal limestone on both sides. In places the vein runs out on the stratification planes or on cross fractures. Good ore is found locally, carrying both lead and copper. At the south face near the Governor line the vein has the usual appearance, but in the center there is an irregular streak, a few inches wide, of sulphide ore with pyrite, quartz, barite, galena, the vein enters contact-metamorphosed limestone. A long drift has recently been extended on level 19 for 2,000 feet south; for a long distance this drift penetrates limestone, which is cut by a tight seam carrying quartz, galena, and zinc blende.

Figures 41–43 represent sections of the deposits south of the shaft.

Mineralized rock containing quartz, limonite, and manganese oxide appears along many of the porphyry dikes in this mine, and much of this material carries a few ounces of silver to the ton.

The ore in Iron Blossom No. 1 is siliceous and contains more gold and copper but less silver than the ore near No. 3 shaft. Much of it has the loose and cellular texture already referred to and is made up mainly of quartz in crystalline crusts and barite plates, and limonite. For a period of three weeks in 1915 the ore assayed 8 per cent of lead, 0.75 per cent of copper, and 0.15 ounce of gold and 20 ounces of silver to the ton. Besides it contained 13 per cent of iron and 50 per cent of insoluble matter. In the southern part of the mine and in the deeper levels it contains bunches of partly oxidized enargite and in places also galena. On an average it may contain $5 in gold and 20 ounces of silver to the ton. As usual oxidation extends to the deepest levels. Spots of unoxidized ore may be found in the deep levels, but they occur as well near the surface. Water stands at level 19.

From the company's published report of 1914 it is seen that the stopes near No. 1 shaft yielded during that year 16,451 tons of ore averaging 5.97 per cent of lead, 0.5 per cent of copper, and 22.77 ounces of silver and 0.139 ounce of gold to the ton.

The so-called East vein, which lies in the limestone 40 to 80 feet from the main vein in the workings south of No. 3 shaft, has also been found lately in level 4 of No. 1 shaft. It contains much limonite, malachite, and azurite and very little galena in a gangue of cellular quartz and barite. In 1914 the ore was stoped in both mines to a width of 6 to 12 feet and 30 feet above the level. Some of this ore is rich in gold.

PROPERTY OF DRAGON CONSOLIDATED MINING CO.

Situation.—The property of this company extends for about 3,000 feet along the southern extension of the Iron Blossom vein, south of Iron Blossom No. 1 to the contact of limestone and monzonite porphyry, and includes also the Dragon iron mine. It is owned by Jesse Knight and associates and in 1911 was managed by L. E. Riter.

Development.—The Dragon vertical shaft is sunk over 100 feet south of the contact between limestone and monzonite porphyry. The altitude of the collar is 6,817 feet, the total depth 1,060 feet, and the lowest level 1,025 feet below the collar. Water has been encountered near the contact of limestone and porphyry on levels 8 and 10. The shaft is intended to develop the ore-bearing veins south of the Iron Blossom, but so far these have not proved to be of great value. The shaft also opens a body of iron ore of considerable importance (p. 258).

Vein north of the contact.—The vein enters the Governor claim 650 feet south of Iron Blossom No. 1 shaft but is not visible in the monzonite porphyry, which here covers the surface. At 800 feet farther south-southwest the vein enters the Opohonga limestone and, beyond that the Ajax limestone, both of which are made somewhat crystalline by contact metamorphism. The vein here shows on the surface in places and has been opened in the Governor, White Dragon, and Black Dragon shafts, all three of which have an altitude of about 7,050 feet. The dip of the limestone is 25°–40° E.

The general course of the vein is N. 35° E. and the dip is 80°–85° ESE. Tower and Smith,[1] who examined the workings near the surface, say that

> Along this fissure occurred, in the Governor claim, quartz and barite with lead and copper minerals. In the Black Dragon claim (south of the Governor) larger ore bodies were found near the surface along the vein, which is intersected by east-west fissures on which some ore had also formed. At the Black Dragon shaft on the 200-foot level an ore body was found at the intersection of fissures; on the 315-foot level the ore alternates on N. 35° E. and northeast fractures.

The vein is narrow and contains silicified limestone and barite as gangue and galena, limonite, and chrysocolla as ore minerals.

The long Dragon tunnel has followed the vein at an altitude of about 6,775 feet from a point near the iron mine on the south for 1,300 feet, to a point 200 feet north of the Black Dragon shaft. This nearly corresponds to the 315-foot level of the Black Dragon shaft. In many places in the Dragon tunnel the vein is tight and shows little mineralization. A shipment of ore from a point between the Black Dragon and White Dragon shafts was made, and it contained 7 per cent of copper and 4 ounces of silver and 0.4 ounce of gold to the ton. Still lower, at an altitude of 6,650 feet, the vein is intersected by a long crosscut on the 300-foot level of the Star mine. Finally, in the Governor claim it is opened from Iron Blossom

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 756.

No. 1 shaft on its level 6 at an altitude of about 6,700 feet and on the corresponding level 3 from the Governor shaft. It is also opened in the same claim for some distance by level 8 of Iron Blossom No. 1, and, as stated above (p. 244), level 19 follows the same vein but in Iron Blossom ground, parallel to the Governor side line for 1,500 feet south.

Throughout these workings the vein, though as a rule small and tight, is well marked by a fissure and some evidence of silicification, but little ore has so far been found. On level 8 the vein is 4 feet wide and shows much limonite and copper stains on the outside and a narrow streak of pyrite, enargite, and barite in the middle. The stopes of siliceous ore on level 5 of Iron Blossom No. 1 have been carried about 100 feet into Governor ground. It is said that commercial gold ore has lately been opened at some places in the Governor claim.

Vein near the contact.—Deeper explorations have been carried on from the Dragon shaft close to the contact of limestone and monzonite porphyry. The vein apparently intersects the body of limonite that occurs on the contact (p. 258), but it is not clear whether the fissure continues into the porphyry. Close examination is difficult, because the porphyry for several hundred feet south of the contact is exceedingly altered, bleached, and kaolinized, as is indeed also the limestone. The underground workings have not reached the igneous rock along the vein, for the contact dips steeply to the south, so that limestone underlies monzonite porphyry. About 800 feet south of the deep shaft is the King James vein, in monzonite porphyry, and as this lies in the general direction of the Dragon vein, it is probable that the vein crosses the contact.

The shaft is sunk in altered porphyry but intersects the contact a little above the 300-foot level. At some places the limestone is rather coarsely crystalline. The geologic conditions at the shaft are described in more detail on page 259.

Fragments of vein matter containing quartz and barite have been found in the iron ore near the surface. A raise from the 300-foot level to the surface has followed vein matter surrounded by and stained with iron hydroxide. A vein in line with the Governor vein is exposed on the 175-foot level; it contains quartz, barite, and a little pyrite. The pyrite is oxidized only in part, though the walls consist of the kaolin which surrounds the iron deposit. Besides these veins several siliceous lenses carrying from 3 to 5 ounces of silver and from 0.01 to 0.05 ounce of gold to the ton have been found in the iron ore. On the 300-foot level the vein has been followed for 400 feet. The same fissure is cut on the 800-foot level, on which it carries barite with a little lead and copper. On the 1,025-foot level (altitude 5,790 feet) the vein shows only silicified limestone. Drifts to the southeast on the 800 and 1,025 foot levels have also disclosed a narrow fissure trending north-northeast 300 feet east of the Governor vein and possibly corresponding to the Turk vein, opened farther north, and to others that extend east-northeast, and show a few feet of altered limestone with quartz and galena. A small shipment from the last-mentioned veins contained 22 per cent of lead and 9 ounces of silver and 0.8 ounce of gold to the ton. All these workings are still in limestone, and though a crosscut has been made in the igneous rock on the 800-foot level the Governor vein is not found in the igneous rock in the place where it should have been cut. On the two lowest levels the igneous rock is not an effusive porphyry but is clearly monzonite, though it is somewhat impregnated with pyrite, sericite, and calcite.

Much of the ore in the narrow veins of the Dragon property shows a relatively high tenor in gold, running as high as $16 to the ton, and contains both copper and lead, though not necessarily together. High contents in gold locally coincide with low contents in silver.

MINES IN THE EAST TINTIC DISTRICT.

By G. F. Loughlin.

The name East Tintic district is here used to represent the area within the Tintic quadrangle east of meridian 112° 5′ and south of the Denver & Rio Grande Railroad. Only two properties in this district have been productive since 1911. These were the property of the East Tintic Development Co., which was being operated under lease, and that of the Tintic Standard Mining Co., which was being prospected.

PROPERTY OF EAST TINTIC DEVELOPMENT CO.

The East Tintic Development Co.'s property is situated 1¾ miles due east of Knightville, where a wagon road crosses the narrow neck of limestone. (See Pl. I, in pocket.) The property extends in a north-south direction from 125 to 185 feet, and its east-west dimension is 700 feet. It lies in the midst of several claims owned by different persons in 1911, and the difficulties attending development work near the boundary lines had then caused a suspension of systematic work pending an attempt at consolidation with the surrounding claims. Since the mine was studied the property has changed owners and a consolidation has been made. Development work below the levels here described was being carried on in the later part of 1916. The company prior to 1911 had mined over 50 carloads of lead ore averaging 42 per cent of lead and 2 to 4 ounces of silver to the ton. Oxidized zinc ore was formerly thrown on the dump, but during the summer of 1912 and 1913 the dump and the lead stopes were worked for zinc ore by lessees. About 1,000 tons of zinc ore was shipped up to July 1, 1913, when the lease expired.

The surface equipment in 1911 included a small steam hoist, a compressor, and a jig. The ore was hauled by wagon to the Iron Spur siding on the Denver & Rio Grande Railroad, 1 mile east of the base of the mountains and 6 miles from the mine. The underground workings included a shaft 500 feet deep (altitude of collar about 6,000 feet), with drifts on the 70, 130, 230, 330, and 500 foot levels. All the levels but the deepest had exposed shipping ore.

The country rock is the Middle Cambrian limestone, including the Herkimer and lower formations. The surface exposures of limestone (Pl. I) are surrounded by the Packard rhyolite, which, to judge from the altitude of rhyolite-covered summits to the north and west, must originally have formed a cover 600 to possibly 1,000 feet thick above the present limestone surface at the mine.

The limestone beds are nearly horizontal, forming a very flat local anticline, or dome, whose axis is close by the mine shaft. Fissures and faults have not been studied in detail on the surface. Those found underground belong to two systems, one trending nearly north and the other N. 70° E. Both have been influential in the concentration of the ore.

The ore body, so far as developed, is a replacement vein, following a general northerly course, with a few enlargements at the intersections of cross breaks or easily replaced limestone beds. There is a small outcrop of mineralized rock a short distance northeast of the shaft, but no work has been done on it in recent years. The highest stope (fig. 44) is on the 70-foot level. Here a strong but barren fissure, striking N. 30° W. and dipping 70° NE.

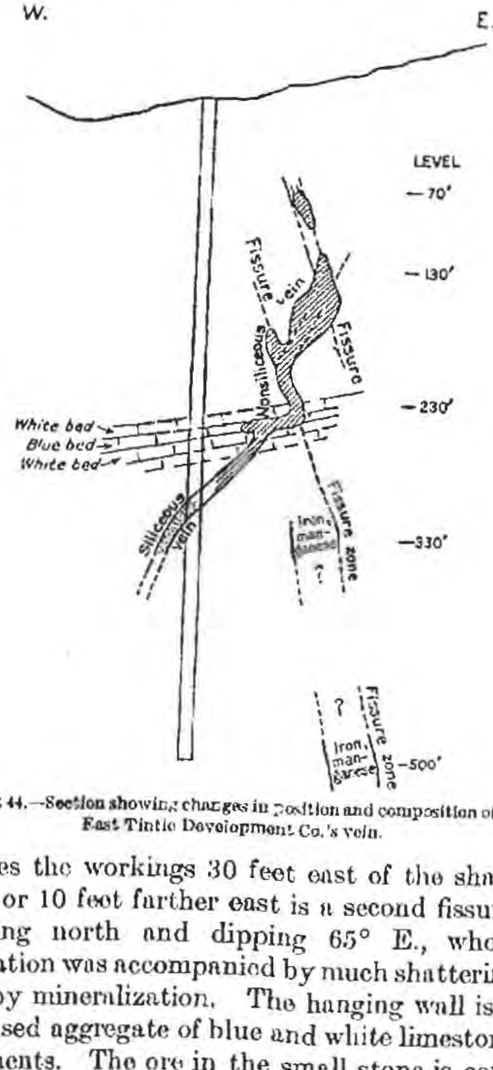


FIGURE 44.—Section showing changes in position and composition of the East Tintic Development Co.'s vein.

crosses the workings 30 feet east of the shaft. At 8 or 10 feet farther east is a second fissure, striking north and dipping 65° E., whose formation was accompanied by much shattering and by mineralization. The hanging wall is a confused aggregate of blue and white limestone fragments. The ore in the small stope is confined to the hanging wall and consists of rather fine grained galena, accompanied by cerusite. It occurs in bunches and boulders, the largest weighing over 1 ton, in a gangue of the white limestone more or less decomposed to a yellowish-brown sandy material. The blue rock is practically absent where ore is prominent

and has evidently been replaced. The ore has also filled small fractures and irregular openings. No quartz nor silicified rock has been found in the ore body on this level. The ore assays only 2 to 4 ounces in silver to the ton.

The same mineralized fissure, dipping 70° E., is cut on the 130-foot level 60 feet east of the shaft. The ore and wall rock present the same characteristics and relations as on the 70-foot level. Only one carload had been shipped from this level up to the time of the writer's visit. This shipment yielded 58 per cent of lead. The ore connects downward with a stope 35 to 40 feet long (from east to west) and 10 to over 20 feet wide (from north to south), which follows a cross break striking N. 70° E. and dipping very steeply southward. This stope has so far yielded the richest ore. Its east end lies 39 feet below the 130-foot level along a N. 15° W. fissure wall and connects on the east with the upper end of a barren cave, which follows a semicircular course from this point down to the 230-foot level. The cave is lined with a white crust of fibrous calcite, upon which the flat calcite rhombs are perched. The west end of the stope is where the downward continuation of the western fissure on the 70-foot level should meet the cross break. On the north side of the cross break the stope pitches northward in pipe form for about 10 feet along a fissure that strikes N. 35° E. and dips about 45° W., beyond which it assumes a veinlike form. The vein follows the west dip to a point 30 feet above the 230-foot level and there swings to an east dip of about 50°. On the 230-foot level the strike of the vein is N. 15° E. and the dip 75° E. Ore has been stoped continuously from the 130-foot to the 230-foot level; the stope length along the vein ranges from 60 to 120 feet and its width from 4 to 10 feet. At 10 feet below the 230-foot level and about 130 feet north-northeast of the shaft a flat, circular shoot about 30 feet in diameter, replacing a blue limestone bed, has been stoped. It spreads from the west side of the vein and ranges from horizontality to a dip of 30° W. Ore from the bottom of this shoot has been followed in a winze down a N. 45° W. dip to a point 51 feet above the north end of the 330-foot level. The ore from the 70-foot level down to the bottom of this winze, a vertical distance of 209 feet, is practically free from quartz. The vein crosses the shaft 30 feet above the 330-foot level and on that level lies 10 feet west of the shaft, striking N. 15°–20° W. and dipping 70° W. South of the shaft its strike curves to northwest. The vein has been followed on the 330-foot level for 100 feet and has a general width of 5 feet, though at one place it bulges to 10 feet. The footwall is well slickensided, and the grooves pitch 60° N.

The primary ore minerals on the 330-foot level are galena and some zinc blende, for the most part in single crystals thickly disseminated, and the primary gangue is chiefly quartz with some barite and fragments of unreplaced wall rock. The quartz is of two generations, as in the Iron Blossom zone, and shows the same leached character in places. The ore occurs in bunches and assays 10 to 15 ounces in silver to the ton. Some oxidized lead and zinc ore is present, also small pockets containing flat calcite rhombs and showing iron and manganese stains.

The main bodies of oxidized zinc ore were mined along the walls of the lead stope between the 230 and 330 foot levels and in the bottom of the stope on the cross break. The ore was evidently concentrated by leaching from the upper levels, downward migration, and replacement of the limestone walls.

At 90 feet northeast of the shaft on the 330-foot level a crosscut passed through about 40 feet of soft ground heavily stained with iron and manganese oxides. A similar occurrence is said to have been found on the 500-foot level 180 feet east of the shaft. These two occurrences are approximately in line with the eastward-dipping portion of the stoped vein on the 230-foot level, but no lead has been found in them. No attempt had been made to cut the main vein on the 500-foot level.[1]

TINTIC STANDARD MINE.

Location and general features.—The Tintic Standard mine lies just east of that of the East Tintic Development Co. and extends about a mile from north to south and less than half a mile from east to west. The old shaft, near the west side of the property, is about 1,500 feet east-southeast of that of the East Tintic

[1] A specimen received in January, 1918, from new works approximately in line with a downward continuation of the vein shown in figure 44 consists of enargite, tetrahedrite, and pyrite with quartz and barite. This may indicate a further change of mineral contents in this vein similar to that in the main ore zones of the Tintic district.

Development Co. It is 1,000 feet deep, with drifts on the 400, 700, 1,000, and "1,200" foot levels, and inclined winzes extending from the 1,000-foot down to the "1,200-foot" level, and from the "1,200-foot" down to the "1,600-foot" level, 1,300 feet below the collar of the shaft. A new shaft, across the gulch to the north of the old shaft, was completed to a depth of 1,260 feet in 1917, and a connection was made with the principal stope on that level. This shaft will greatly facilitate handling of the ore and will improve the ventilation of the mine, which has heretofore been so poor as to impede working.

At the surface the Packard rhyolite and the underlying bed of rhyolite tuff rest upon the Teutonic limestone. The underlying shale is either exceptionally thin at the shaft or is locally eliminated by obscure faulting; for the shaft is said to extend for about 650 feet through limestone of prevailingly shaly character and then to pass through a small thickness of shale and to reach at a depth of 670 feet the Tintic quartzite, which persists to the 1,000-foot level and beyond. The northwest dip of the strata brings the quartzite and shale contact to the 1,000-foot level along the northwest drift. There is a pronounced seepage of water from the shale, but permanent ground-water level has not been reached. At the 700-foot level the shaft passes through a faulted anticlinal axis of northeasterly trend, the strata dipping 20°–25° to the southeast and northwest. The shale exposed on the 700-foot level is only 20 to 25 feet thick and is greatly kaolinized. Two decomposed rhyolite dikes have been cut, one near the shaft on the 700-foot level and the other near the north end of the 400-foot level.

An easterly fault zone with down slip to the north extends along the gulch just north of the shaft. A strong gossan-stained quartz outcrop lies in or closely parallel to this fault zone on the north wall of the gulch. A few prospect holes have been dug along it, but no promising quantities of ore have been found.

Lower workings.—The principal ore zone is along the contact of quartzite and shale, from the 1,000-foot down to the "1,600-foot" level, about 1,300 feet below the collar of the shaft. The northeast drift of the 1,000-foot level, reached by a northwest crosscut from the shaft, follows the quartzite and shale contact, which at short intervals is offset from a few inches to 3 or 4 feet by vertical slips of northward trend. The shale is soft and partly kaolinized, resembling decomposed rhyolite porphyry. The ore forms small pockets or bunches along the contact, mostly replacing the quartzite but also replacing shale to some extent. The first shipping ore was found late in 1913 on the 1,000-foot level about 950 feet north of the old shaft. About 40 tons was shipped, netting over $40 a ton. The silver content, which was low elsewhere on this level, was high at this place, but thorough alteration of the rocks prevented recognition of any fissures in connection with the higher-grade ore.

The ore on the 1,000-foot level is principally galena, accompanied by minor amounts of very fine grained pyrite, zinc blende, and tetrahedrite. The galena consists of fine irregular to cubic grains and around small vugs forms cubes with truncated corners. Specimens of galena in shale show a finely streaked or feathery texture resembling that of the sulphantimonite jamesonite, but blowpipe tests failed to detect any antimony. The pyrite occurs in minute scattered grains and in small linear streaks. The zinc blende forms scattered grains inclosed in galena or pyrite. It is so fine as to escape detection in most specimens but is readily found in thin section. Tetrahedrite mixed with galena and pyrite is prominent here and there, especially along the southwestern part of the drift, where it forms a streak 2 to 6 inches thick and is said to assay as high as 80 ounces of silver to the ton and 22 per cent of copper. The gangue is chiefly quartz with varying amounts of barite. The barite appears to be most abundant where the copper minerals are conspicuous. The quartz is not prominent in the highest-grade ore specimens but in thin section is seen to comprise over 50 per cent (by volume) of the whole. In character the quartz ranges from quartzite with the original sand grains showing secondary enlargement to recrystallized quartz with distinct prismatic outline. The ore minerals occur largely as a continuous network in the interstices among the sand grains and in places as small solid masses completely replacing the rock. In the shale the ore and gangue minerals lie mostly in openings along the lamination planes and minute cross fractures, but they replace the rock to some extent. Where it is replaced the shale, originally composed for

the most part of microscopic quartz and sericite, has changed to a mass of very fine grained, practically barren quartz. The zinc blende, galena, and barite are confined to the fractures or the rock immediately adjacent. The pyrite, however, is scattered all through the shale, as single granules and as minute fracture fillings.

Partial oxidation has developed cerusite and locally malachite and azurite, also more or less limonite and a little calcite. Some bunches of lead ore are entirely changed to cerusite. The winze, which follows the contact down to the "1,200-foot" level, has shown the ore bunches to continue to that depth, but none large enough to constitute shipping ore have been found. A showing of zinc ore is said to have been found in this winze.

The high-grade ore on the 1,000-foot level was followed by an inclined winze down the dip for about 70 feet to the "1,100-foot" level, where short drifts were driven in ore for 40 to 50 feet on each side of the winze, yielding three carload shipments. About 70 feet farther down the winze and 15 feet above the "1,200-foot" level another shoot, 50 feet long and 10 to 15 feet wide, was mined, the stope trending about N. 25° E., or about parallel to the prevailing system of northerly fissures. Ore shipped from this stope and the "1,100-foot" level was considerably oxidized. It contained 0.06 to 0.165 ounce of gold and 5.05 to 8.7 ounces of silver to the ton; 18.7 to 35.65 per cent of lead, 26.75 to 52.5 per cent of insoluble matter, 1.2 to 4.55 per cent of sulphur, and 9.9 to 14.7 per cent of iron. The gold content in this ore is considerably higher than that in ore at lower levels and may signify a small degree of enrichment. The ratio ounces of silver to per cent of lead is low, ranging from 0.19 to 0.27, the quantity of silver varying directly, though not uniformly, with that of lead.

At the "1,200-foot" level the winze entered a small shoot of oxidized zinc ore, which had a maximum thickness of 6 feet, thinning both to the east and to the west, and which yielded a carload shipment. The ore still shown in the east face of the stope is brown fine-grained smithsonite that contains drusy vugs and is similar to the "brown zinc" ore of the May Day, Yankee, and Gemini mines. It is said to contain an average of 33 per cent of zinc. So far as could be determined in the iron-stained walls of the stope, the smithsonite had been formed by the replacement of a small lens of limestone just above the quartzite.

From this stope the "1,200-foot" level was extended eastward for about 150 feet along the mineralized contact of quartzite and shale, which consisted, as elsewhere, of yellow and brown stained quartz, with a low content of galena and cerusite. Where indications were most promising along a marked fissure zone trending about N. 25° E. another winze was sunk along the dip for 380 feet to the "1,600-foot" level (1,300 feet below the collar of the shaft), and an east drift, the "1,550-foot" level, was run from it 330 feet down the incline from the "1,200-foot" level. At the top of this winze, called the lower winze, a small shoot of copper minerals, similar to those on the 1,000-foot level, was mined, the ore containing 0.025 ounce of gold and 17.6 ounces of silver to the ton, 10.18 per cent of copper, 50.0 per cent of insoluble matter, and 13.2 per cent of iron. Small bunches of copper minerals were found for some distance along the incline.

A short distance above the "1,550-foot" level the dip steepens, taking the quartzite below the floor of the winze. On the "1,550-foot" level silicified shale and perhaps shaly limestone, more or less brecciated and iron stained, are prominent along fractures. This material was mined along the drift for about 100 feet and contained 0.01 to 0.02 ounce of gold and 8.80 to 17.05 ounces of silver to the ton, 2.65 to 16.90 per cent of lead, and 0.20 to 0.37 per cent of copper. Returns on one shipment having average lead and silver content showed 64.6 per cent of silica, 3.10 per cent of sulphur, 9.8 per cent of iron, and 1 per cent of zinc. In thoroughly oxidized material along northerly fissures and minor fractures as high as 400 ounces of silver to the ton, partly in the form of wire silver, was reported. The silver in this ore is most abundant where lead is least, and the wire silver in oxidized material signifies enrichment.

This siliceous ore as a whole consists of dark-gray dense quartz, with very fine, evenly scattered grains of pyrite and with thin streaks of galena and cerusite along original bedding planes. Microscopic sericite is in places sufficiently abundant to render the rock a little softer than steel. In thin sections it appears as a fine-grained feltlike mass of quartz

and sericite, with thickly disseminated pyrite, containing parallel bands of galena and relatively coarse prismatic grains of quartz. The galena is in part replaced by cerusite, which is accompanied by a little kaolin. The quartz and shale of the pyritic portion may be interpreted as mostly a recrystallization of the constituents of shale or shaly limestone, but the predominance of quartz also indicates an addition of silica. A specimen of the brecciated rock consists of inclusions of silicified shale as much as half an inch in diameter slightly impregnated with extremely fine grained pyrite, in a siliceous matrix of less fine grain containing pyrite, galena, and a little barite. In thin sections the inclusions consisted mainly of very fine grained quartz, sericite, and pyrite, with here and there a relatively large, partly developed crystal of quartz. The matrix consisted mainly of coarser grains of the same minerals, the quartz mostly in rather well developed crystals and the sericite partly segregated into tuftlike aggregates. Pyrite as a whole presents distinct crystal boundaries but incloses and is intergrown to some extent with quartz and sericite. The galena shows similar relations to quartz and sericite, but has only irregular outlines. The barite forms typical tabular crystals of synchronous growth with some of the quartz, but also cut and replaced by veinlets of quartz and sericite. These relations of the minerals to one another are generally similar to those in the main ore zones of the Tintic district.

The siliceous body just described in part overlies the principal stope of the mine, opened just west of the bottom of the winze on the "1,600-foot" level. This stope when visited (Dec. 11, 1916) was of rectangular outline, extending 110 feet in a northerly and 60 feet in a westerly direction, and was 12 to 14 feet high, with ore still showing in the roof and on the east, west, and south sides. Its southeastern part had been extended beneath the winze.

The north face of the stope consisted of silicified shale beds dipping southward at a low angle and indicating a local shallow troughlike structure. No trace of quartzite was found, even at the south end of the stope, and it is therefore inferred that a cross break or easterly fault exists between the south end of the stope and the point where the quartzite disappears below the floor of the winze, its exact position concealed by silicification. Such a fault in the quartzite may be represented by a flexure or "roll" in the shale. Besides this fault and the northerly fissure zone followed by the winze, two other northerly fissures were noted in the stope. The ore shoot appears to owe its existence, therefore, to the opening up of the strata where the northerly fissures intersect the easterly fault.

The ore in the main stope consists of alternating layers of high-grade and low-grade galena. A little high-grade cerusite was exposed in the roof of the stope. The high-grade layers evidently replaced shale along the more open bedding planes and doubtless replaced any beds or lenses of limestone that were present in the shale. No remnants of unreplaced limestone were found. The high-grade galena consists of aggregates of grains 3 millimeters or less in diameter, in which are scattered lenses from half an inch to 2 inches long of fine-grained galena. There is nothing to indicate that the fine-grained galena was deposited later than the coarse. The fine-grained galena is also associated with small crystals of barite and pyrite at the borders of the high-grade layers. Only a very little pyrite and gangue are found within the high-grade galena. Polished surfaces of the galena are seen under the microscope to inclose scattered minute crystals of pyrite and droplike or irregular grains of argentite, none of which showed indications of secondary origin. A few specks of an unidentified mineral with lighter-gray surface than argentite were also noted.

A thin section of the gangue showed it to consist of barite in typical crystals, with fine fringes of sericite, which separated it from galena. A little sericite was inclosed in the galena, but quartz was inconspicuous.

The lower-grade layers represent the less permeable beds of shale. In places these layers consist of thin parallel streaks of galena and cerusite along bedding planes in a partly decomposed pyritic shale showing small white spots of kaolin. These spots have some resemblance to phenocrysts of feldspar in altered porphyry, and this variety of the ore has accordingly been termed "porphyry ore." No true porphyry has been found in or near this stope. Thin sections of this shale or "porphyry" show it to consist of fine-grained quartz and sericite accompanied by very fine grained

pyrite and partly developed crystals of quartz. These quartz crystals form the greater part of the "porphyry ore" and are accompanied by pyrite and layers of galena. Sericite is confined to the less silicified remnants of shale. Weathering processes have changed pyrite to hematite and limonite, galena to cerusite, and the remnants of shale to kaolin.

The principal metal content of ore shipped from this stope up to December 8, 1916, ranged as follows: Gold, 0.01 to 0.016 ounce to the ton; silver, 8.4 to 33.25 ounces to the ton; and lead, 9.60 to 37.35 per cent. Other constituents determined in a few shipments ranged as follows: Copper, 0.15 to 0.20 per cent; zinc, 0.40 to 1.30 per cent; insoluble matter, 38.20 to 61.5 per cent; sulphur, 0.45 to 9 per cent; and iron, 9.05 to 16.3 per cent.

The ratio ounces of silver to per cent of lead varies widely, from 0.41 to 1.38. The silver content up to 20 ounces to the ton varies for the most part directly, though not uniformly, with that of lead. As the silver content rises above 20 ounces to the ton the lead content tends to decrease, though not uniformly. These data suggest that a silver content in excess of 20 ounces to the ton may be due in part to enrichment, but no proof of enrichment, either megascopic or microscopic, could be established in the ore available for examination by the writer.[1]

Since the writer's last visit to this mine, in December, 1916, the new or northern shaft, having three compartments, has been completed to a depth of 1,300 feet. According to Mr. E. J. Raddatz, manager of the mine, the upper 525 feet of this shaft is in porphyry (rhyolite), and the remainder in "Mammoth" (doubtless Middle Cambrian) limestone. Ore was struck in this shaft at a depth of 1,174 feet and continued beyond the bottom of the shaft. This ore is associated with a fissure striking about N. 10° E. and dipping 80° E. A suite of ore samples from the shaft were sent to the writer by Mr. Raddatz. One from a depth of 1,180 feet consisted of fine-grained galena and tetrahedrite with a little pyrite in a gangue of barite and cherty replacement quartz. Four specimens from a depth of 1,250 feet range from fine-grained massive galena with very little pyrite to fine-grained massive pyrite with little galena. A little zinc blende is also present. The tetrahedrite and barite are said to disappear and galena and pyrite to become more prominent at a depth of 1,220 feet.[2]

The ore in the lower workings of the Tintic Standard mine is generally similar in metal content to the silver-lead ore in the Iron Blossom zone between the Spy fault and the Yankee mine, and in the Eagle and Blue Bell, Chief Consolidated, and Gemini mines of the western ore zones of the Tintic district. The relatively higher silver-lead ratios in the ore on the "1,600 foot" level indicate that it is in or near a main channel of ore deposition, whereas the lower ratios on the "1,100-foot" and "1,200-foot" levels suggest a more remote position. The site of intense ore deposition in this part of the mine is evidently the intersection of the easterly fault with the quartzite-shale contact and with associated northerly fissures. The ore solutions doubtless rose through the quartzite along northerly fissures in this vicinity, as in the Tintic district to the west, and spread where these fissures were interrupted or tightened at the quartzite-shale contact; but the opportunity to deposit commercial quantities of ore in these relatively unfavorable rocks was afforded only where disturbance along the easterly fault had rendered the rocks more permeable. The ore body found in the new shaft is presumably, like that in the East Tintic Development vein, a replacement vein deposited where solutions worked their way through a much shattered part of the shale into the overlying limestone. Further developments in this part of the mine should afford interesting data regarding the occurrence and distribution of ore shoots.

Upper workings.—A small bunch of ore is said to have been found along the quartzite and shale contact on the 700-foot level. The southeast drift on this level passes obliquely across an easterly fissure, probably a fault, along which small pockets have been dissolved in the quartzite. The pockets are imperfectly lined with small, poorly formed quartz crystals,

[1] The value of shipments from this stope was sufficient to put this mine in the group of dividend payers in 1917.

[2] In January, 1918, a new ore body had been opened on the 1,200-foot level, close by the new shaft, for a length of 60 feet. It has yielded some very rich ore, 2 carloads averaging 90 cents in gold and 333 ounces of silver to the ton, 10 per cent of copper, and 4 per cent of lead. Picked samples have assayed over 1 ounce of gold and 2,000 ounces of silver to the ton. In specimens sent to the writer the primary ore minerals are tetrahedrite, enargite, pyrite, and galena; the secondary minerals are native silver and copper, malachite, azurite, and chalcocite.

and some are said to have contained a little copper mineral.

On the 400-foot level a northerly fissure in shaly limestone has been cut about 375 feet due southeast of the shaft. Where followed it is slickensided and generally tight but contains small streaks of galena mixed with an inconspicuous quartz gangue.

On the north drift of the 400-foot level, 50 to 90 feet north of the eastward-trending gulch and under the quartz outcrop, is a considerable body of brown iron and black manganese oxides mixed with kaolin. It has replaced the shaly limestone along a fissure. It extends on both sides of the rhyolite dike, which is cut by the fissure. The dike, though kaolinized, has not been conspicuously stained by iron or manganese oxides. A little quartz or silicified limestone along the fissure remains unreplaced. The replacing minerals are not sufficiently separated to make ore of shipping grade. In other respects the body is of the same general character as the Dragon iron deposit.

A striking feature of the mine is the high temperature (93° F.) of the lower workings and the presence there of a gas of more or less sulphurous odor. The level to which this gas rises in the mine fluctuates with the barometric pressure. Air is forced into the mine for ventilation. When the barometric pressure is high the gas is kept at the floor of the 1,000-foot level, but when it is low the gas may rise as far as the collar of the shaft and prevent working for hours or even days. No gas was struck until the shaft was sunk into the quartzite. The only reasonable explanation based on available data seems to be that oxidation of the pyrite which is disseminated through the shale, supplemented by the sulphide minerals in ore bunches, has left an excess of nitrogen and has generated heat and sulphurous anhydride, also sulphuric acid, which would react with any limestone layers in the shale and generate carbon dioxide. The impervious character of the shale would tend to keep these heavy gases from ascending and would force them to accumulate in the quartzite. The presence of iron oxide deposited by water seeping from the shale, the corrosion of pipes and rails in the drift, and efflorescence on the walls and on dried shale specimens of iron, aluminum, calcium, and alkali sulphates all lend support to this explanation.

FUTURE OF THE EAST TINTIC DISTRICT.

By G. F. Loughlin.

Work in the Tintic Standard and East Tintic Development mines has proved that ore has been deposited there in considerable quantity in rocks that in the Tintic district proper lie west of the four ore zones and are regarded as relatively unfavorable for ore deposition. The mild degree of metamorphism in the limestone less than a mile south of these mines, together with the presence of dikes and small irregular intrusions of monzonite porphyry, indicates a minor intrusive center there as the most probable source of the ores in the East Tintic district. The solutions from this source, however, had to ascend through the Cambrian quartzite before reaching the limestone, whereas in the Tintic district proper they passed from the main monzonite mass directly into the limestone. Owing to the nearly horizontal position of the sedimentary rocks in the East Tintic district, the shale formed an effective barrier to the ore solutions that rose through the quartzite, and owing to the low degree of permeability of both these rocks the solutions spread along the quartzite-shale contact, forming for the most part thin layers of low-grade ore, with local small bunches of high-grade ore. Only where the rock was sufficiently shattered at the intersection of northerly fissures with easterly faults or cross breaks was ore deposited in large shoots along or near the contact.

Where fissuring was sufficiently strong to afford passage upward through the shale, the solutions reached the limestone; but the limestones above the shale are not so favorable for ore deposition as the limestones that contain the main ore zones in the Tintic district. Ore in commercial quantity, however, as shown by the East Tintic Development vein, and perhaps also by the ore in the new Tintic Standard shaft, was deposited along pronounced fissures, especially at their intersections with cross breaks and local replaceable beds, and detailed work with a view to locating the principal fissure zones and the purest limestone beds may result in the discovery of additional ore bodies.

The solutions on passing through the shale were not only depleted of part of their metal content but were cooled and diluted with waters already in the limestone, factors which lessened their power to form extensive replacement

deposits. Such solutions may travel considerable distances without finding a favorable place to deposit ore and may therefore give rise to small scattered shoots remote from the source of mineralization instead of continuous ore bodies. Such scattered deposits are characteristic of other parts of Utah where similar conditions existed and may be expected in the limestones of the East Tintic district for some miles northward from the present productive mines. Ore characteristic of such solutions is comparatively low in silver, and its deposition is accompanied by relatively little silicification.

The finding of new ore bodies obviously depends in large part on a detailed study of the district to locate the principal mineralized northerly fissures and cross breaks, the quartzite-shale contact, and the more replaceable limestone beds. It should be borne in mind, however, that mineralized fissures in outcrops of limestone, and especially in the rhyolite area, may be a long way from deposits of commercial size and not directly connected with such deposits. Reference to the geologic map (Pl. I, in pocket) shows that the sedimentary rocks are dislocated by easterly and northerly faults of considerable size and older than the rhyolite. There are strong chances, therefore, of miscalculating the depth of the quartzite-shale contact.

When the distribution of known ore zones in the Tintic and East Tintic districts and their relations to monzonite intrusions are considered, it is reasonable to expect that at least one more zone may exist between the East Tintic Development vein and the Iron Blossom zone, but results of prospecting at shallow depths in this area have thus far been negative. The existence of ore zones beneath the rhyolite east of the Tintic Standard zone is also a possibility; but no evidence of mineralization of the rhyolite sufficient to serve as a guide in prospecting has been noted.

MINES IN THE IGNEOUS ROCKS.

SWANSEA MINES.

The Swansea mines, owned by the Swansea Consolidated Mining Co., are just north of Silver City, in the southern part of the quartz porphyry area. The former Swansea and South Swansea, with the Four Aces and some smaller properties, are now consolidated and worked through the South Swansea shaft. The original Swansea mine, according to the earlier report,[1] was productive from the earliest times up to 1896 in a more or less satisfactory manner and since 1896 has yielded a large amount of argentiferous galena. The earliest work was done in the oxidized zone, which was rich in silver and lead carbonate to a depth of 250 feet. The mining was carried on, for the most part, in the tunnels and winzes north of the shaft. At a depth of 250 feet barren pyrite was met, and practically all work ceased. In the spring of 1896, however, at a depth of 350 feet, argentiferous galena and lead carbonate were found which, to judge from the mine map, lead to the largest shoot (see. fig. 45) in the entire workings of the consolidated mines. The history of the original South Swansea mine follows closely that of the Swansea. There was an early period when ores of considerable value were taken from the oxidized zone, then a period of idleness covering many years, and finally the striking of rich ores below the barren pyrite soon after they were found in the Swansea.

The underground workings (fig. 45) consist of a shaft 940 feet deep, with north and south drifts at various levels, but the only accessible workings during the writer's visit were on the 700-foot level, which was being operated under the leasing system. A station was then being cut on the 940-foot level, and drifting on that level has since been carried on. Data from other workings are taken from the earlier report.[2] Water was struck at a depth of 650 feet and in 1911 was raised by a steam pump installed on the 700-foot level.

The wall rock is Swansea rhyolite down approximately to a depth of 900 feet, below which the shaft is in monzonite. The contact dips steeply westward.

The vein has been worked through a horizontal distance of 2,000 feet, from the Four Aces shaft northward almost to the summit of the ridge. Its general trend in the old Swansea ground is N. 10°–15° W., but it bends in places to due north. Its dip as a rule is 70° W. to 90° but in places swings steeply eastward. In the South Swansea ground it follows for the most part a northerly fissure dipping 85° W. to 90°. This fissure near its north end curves slightly eastward and joins a N. 55° W. fissure dipping

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 757.
[2] Idem, pp. 757-759.

70° or less to the northeast, along which the vein extends and connects with the Swansea fissure. The two main portions of the vein overlap only slightly and die out within a short distance beyond the cross fissure, leaving a barren clay seam.

Two short spur veins have been found in the old Swansea ground. One is a vertical vein on the 300-foot level 25 feet west of the main vein, which here dips east but which before reaching the level above bends and follows the spur vein fissure. The other is on the 00-foot level, east of and parallel to the main

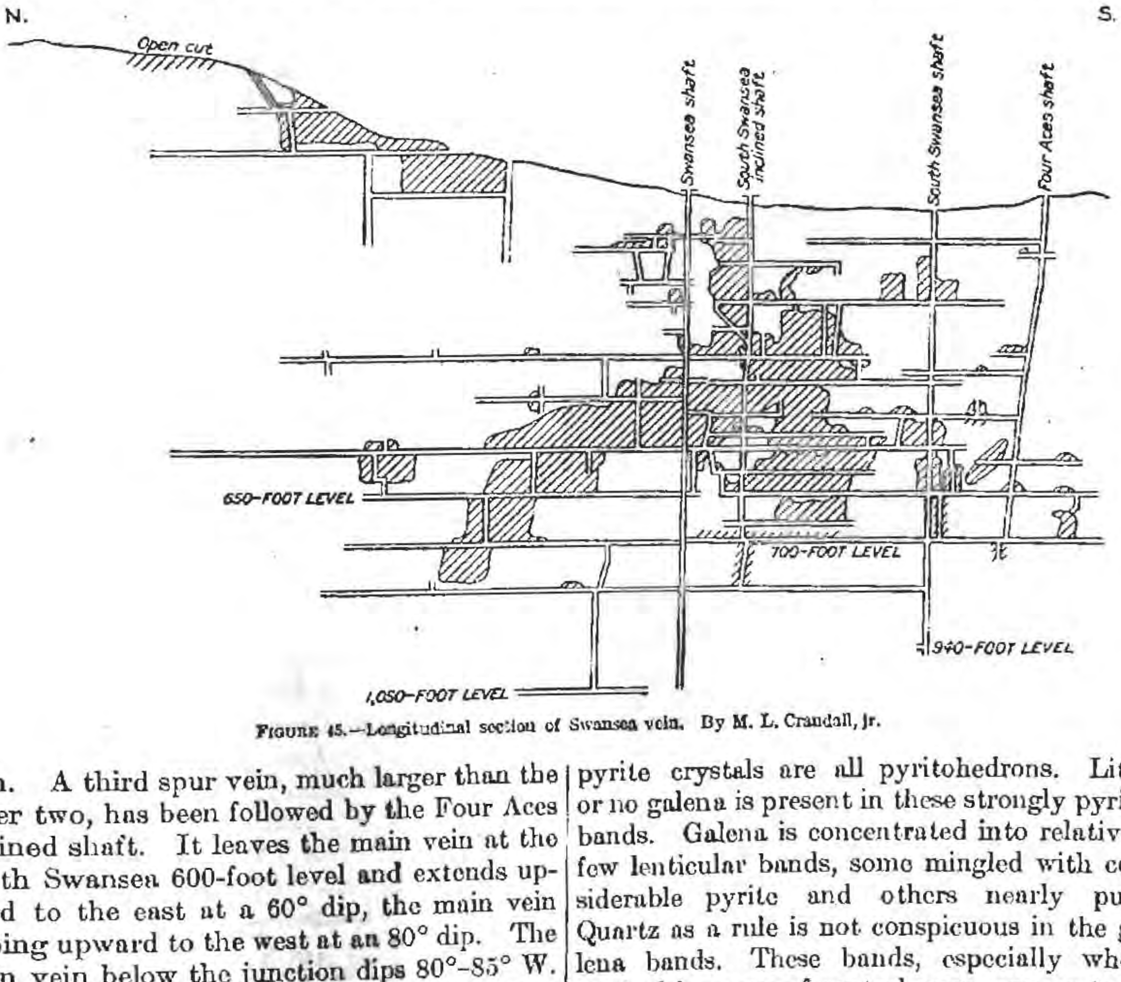


FIGURE 45.—Longitudinal section of Swansea vein. By M. L. Crandall, jr.

ein. A third spur vein, much larger than the ther two, has been followed by the Four Aces nclined shaft. It leaves the main vein at the outh Swansea 600-foot level and extends upard to the east at a 60° dip, the main vein loping upward to the west at an 80° dip. The nain vein below the junction dips 80°-85° W. o the lowest workings. Recent fractures rending N. 55° W. and N. 70° W. seen during he earlier survey[1] have faulted the vein ightly on the 400 and 450 foot levels.

The vein thus follows a zone of linked and ranching fissures. Its average width is about feet, but it varies greatly, from a mere streak o as much as 10 feet. Its walls are in some places sharp and in others poorly defined, the vein matter grading into the country rock. The vein matter consists of quartz, pyrite, galena, a little zinc blende, and a very little arsenopyrite, besides the oxidation products, which are mostly limited to the 600-foot and higher levels. The vein minerals where seen on the 700-foot level, and elsewhere, as described in the earlier report,[2] are arranged in bands. Some bands consist of quartz and pyrite, massive or in well-formed crystals around small vugs; others are narrow bands or lenses of almost solid pyrite. The well-formed pyrite crystals are all pyritohedrons. Little or no galena is present in these strongly pyritic bands. Galena is concentrated into relatively few lenticular bands, some mingled with considerable pyrite and others nearly pure. Quartz as a rule is not conspicuous in the galena bands. These bands, especially where marked by rows of central vugs, appear to lie along original fractures separated by vertical sheets of quartz porphyry now partly or completely replaced by quartz and pyrite, but the broader bands have both filled open fractures and replaced intervening slabs of wall rock. The bands seen on the 700-foot level were mostly only 1 inch to 3 or 4 inches wide, but at

[1] Idem, p. 759.

[2] Idem, p. 758.

the north end a body of ore (pyrite and galena) 2 feet thick and 20 feet long (vertical extent not known) was being mined. A section made across the vein on the 500-foot level of the old Swansea mine during the earlier survey showed 18 inches of pyrite and galena, 18 inches of galena and quartz, 30 inches of pyrite and quartz, 6½ inches of galena, 3 inches of pyrite, and 3 inches of galena. The only other minerals seen in the ore from the 700-foot level were a few very small crystals of arsenopyrite (?) and irregular grains of chalcopyrite. A little sphalerite was found during the earlier survey. No barite has ever been reported. Coatings of blue melanterite crystals are now forming along the drift walls.

The whole vein, according to the mine maps furnished by the company, consisted of two main shoots with several small ones. (See figs. 45 and 46.) The northern of the two main shoots on the upper slope of the ridge extended almost continuously along the surface for 600 feet or more and reached a maximum depth of 130 feet. The other shoot has been stoped continuously from a point within 40 feet of the surface to a maximum depth of 790 feet and through a maximum horizontal distance of 900 feet between points 100 feet north of the present South Swansea shaft and 500 feet north of the old Swansea shaft. The general shape of the stope is that of a T, with the stem pitching 35° N. The smaller stopes in part lie just to the north but mostly to the south of the second large stope. The northern stope and the upper portions of the southern stope yielded lead carbonate ore carrying considerable silver. The southern stope below the 350-foot level yielded mixed carbonate and sulphide ore, the carbonate diminishing downward and disappearing at ground-water level.

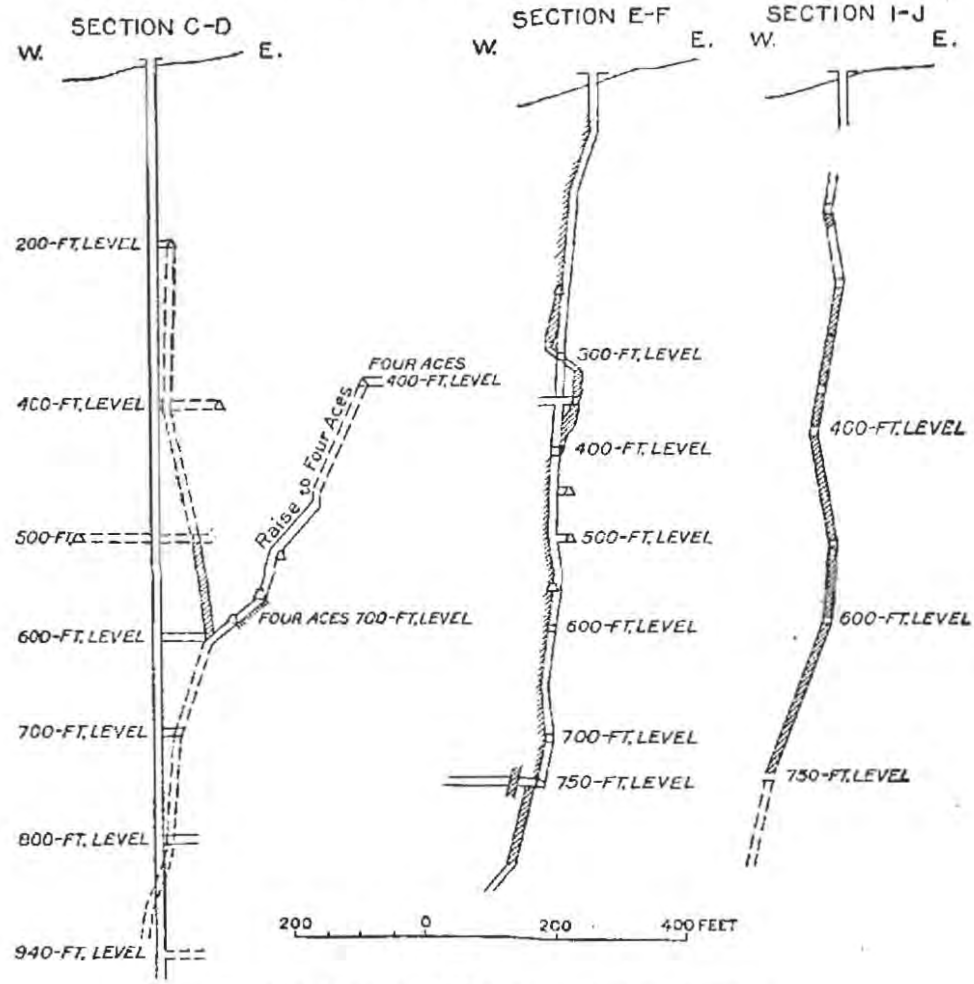


FIGURE 46.—Cross sections of Swansea vein. By M. L. Crandall, jr.

The ores were originally sorted into three classes—galena and pyrite, pyrite, and carbon-

ate; the last is now exhausted. The galena and pyrite ore, as stated in the earlier report, averaged 50 ounces of silver to the ton, 20 per cent of lead, 30 per cent of iron, and 15 per cent of silica; the pyrite ore, 25 ounces of silver, 7 per cent of lead, 38 per cent of iron, and 13 per cent of silica; and the carbonate ore, 90 ounces of silver, 40 per cent of lead, 20 per cent of iron, and 12 per cent of silica. Smelter returns furnished by the company during the recent survey give the following figures:

Smelter returns on ore from Swansea mines.

	Gold.	Silver.	Copper.	Lead.		Speiss.	Silica.	Iron.	Sulphur.	Zinc.	Lime.
				Wet assay.	Fire assay.						
	Ounce.	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Minimum	0.01	12.4	0.0	2.5	4.8	0.9	10.8	23.5	19.0	0.0	0.0
Maximum	.08	48.6	.6	23.6	21.8	5.4	28.2	37.8	41.7	2.5	1.0
Average of 15	.03	30.7	.26	11.6	13.5	2.9	19.0	31.0	31.4	.9	.5

The practical absence of gold in the presence of so much pyrite is noteworthy. The silver varies in quantity with the lead as a rule, but some pyrite bodies are said to carry enough silver to make ore. Of this class is evidently the ore mined on the 940-foot level since the writer's visit, which is reported (an average for 60 days' production) to run 0.03 ounce of gold and 12.2 ounces of silver to the ton, 37 per cent of iron, and 12 per cent of insoluble matter. The negligible amount of copper is striking, in contrast to its abundance in other mines. The speiss evidently represents the arsenic from arsenopyrite, as no enargite has been recorded, and its absence is confirmed by the almost total absence of copper. The zinc, in sphalerite, is irregularly distributed, but even its maximum quantity is negligible commercially. Calcite and dolomite are practically absent in the gangue.

OTHER PROPERTIES.

In the earlier report mention is made of a number of properties which now are mostly idle and the workings of which are largely caved. The following notes are taken largely from that report.

South and east of the Swansea are the Four Aces, Park, Silver Bow, Monterey, Iron Duke, and Yankee Girl properties. The veins are distinct, but so far little ore has been extracted. A shaft on the Iron Duke is 370 feet deep, with water level at 100 feet and a heavy flow of water, amounting to 1,000 gallons a day, on the 350-foot level. The Yankee Girl is understood to have yielded a considerable amount of oxidized ore.

Farther east are the Cleveland, Murray Hill, Rabbit's Foot, and Primrose claims. The Primrose has a shaft 230 feet deep.

About a mile east of Silver City are the Sunbeam, Undine, Lucky Boy, Joe Daly, and Triumph claims, and a quarter of a mile southwest of these lies the Shoebridge Bonanza. Several of this group have yielded ore during late years.

The Sunbeam is the oldest mine in the district and has been opened to a depth of 490 feet. A strong vein has been followed for 4,000 feet, the strike being N. 25° E. and the dip steep or vertical. Just below the Sunbeam shaft the vein sends off a strong branch to the south. The greatest width is 10 feet. The Sunbeam vein has been productive throughout its length, but no ores of high grade have been found below the water level. It is reported that the Sunbeam mine alone, representing only about one-sixth of the length of the vein, has yielded over $500,000 in oxidized ore. Such a vein would seem to have possibilities in depth, but a very heavy flow of water, encountered at 490 feet stopped operations.

The Undine vein has been developed to a depth of 350 feet and is traceable on the surface for nearly 2,000 feet. The vein strikes northeast and dips 50°-80° NW.

The Martha Washington, King James, and Brooklyn are situated north-northeast of the Sunbeam, just south of the contact. From the Brooklyn claim mainly limonite had been shipped, occurring on the contact (p. 258). The Martha Washington and a number of parallel veins are traceable almost up to the contact,

but none of them have been followed across it. The Martha Washington vein is traceable with interruptions for 3,000 feet south-southwest to the Triumph. The Martha Washington shaft is 350 feet deep, and the ore, to judge from the dump, contains much massive pyrite and some enargite.

Near Ruby Hollow, in the southeast corner of the area shown on Plate IV (in pocket), are several prospects on veins in the white altered monzonite porphyry. The New State property has four veins, none of them over 2 feet in width, which strike northeast and dip 60° W. The ore is siliceous and contains tetrahedrite and chalcopyrite.

In the Diamond district, south of the area shown on Plate IV and about 2½ miles southeast of Silver City there are a considerable number of prospects, but few of them are worked at present. The veins contain pyrite, enargite, and some galena in a siliceous gangue; they trend north or north-northeast. At the Treasure Hill mine, which is said to have produced large amounts of ore in the past, the sulphide zone was found 250 feet below the collar of the shaft. Below this not much progress was made on account of heavy water. The Homestake mine has likewise produced much ore during the early history of the district. Its ores carry both gold and silver, with enargite and galena. The oxidation extends to a depth of about 200 feet.

The Treasure Hill mine has a shaft 225 feet deep. The vein has the unusual strike of N. 30° W., dips northeast, and is 2 to 4 feet wide.

The Old Susan mine, owned by the Old Susan Mining Co., is on a low westward-sloping spur about 2 miles south-southwest of Diamond and 1 mile S. 53° W. from the western summit of Sunrise Peak. The mine has been worked intermittently for several years, and from 1909 to 1911 was operated under a lease. The ore shipped has contained lead and silver and occasionally some gold. The work has evidently been carried on wholly by hand. The underground workings include, besides an old open cut, a shaft, a tunnel trending S. 40° E. and cutting the vein at a depth of 317 feet, two crosscuts, and stopes in the vein above the tunnel level. No water has been met. The ore mined, which at present is sandy lead carbonate, is sent down to the tunnel level through a chute, trammed to the surface, screened, and hauled by wagon to the railroad at Silver City, 4 miles away. The shipping ore has run 8 to 17 ounces of silver to the ton and 25 to 40 per cent of lead.

The country rock is the monzonite porphyry, which is intrusive into the tuff and agglomerate of the Volcano Ridge mass. The intrusive contacts exposed in the tunnel are vertical. The vein, so far as mined, lies wholly in the monzonite porphyry.

The vein crops out along the top of the spur, with a N. 52° E. strike and vertical to very steep northwest dip. It has been stoped continuously from close to the surface down to a depth of 100 feet or more and in its widest part is from 15 to 30 feet wide. The walls in the few places that could be examined closely were stripped clean of ore, and the only unoxidized materials found were a few fragments of galena-pyrite-quartz ore of the Swansea type. The relation of the vein to wall rock, whether sharply defined or gradual, could not be studied. The ore thus far mined, to judge from the ore pile, is thoroughly oxidized to sandy lead carbonate and limonite. Lumps of low-grade or barren quartz are removed by screening. The vein matter exposed in the tunnel consists of kaolinized porphyry and quartz, both sprinkled with pyrite and both brecciated. No galena was seen on the tunnel level.

IRON-ORE DEPOSITS ALONG THE CONTACT.

DRAGON IRON MINE.

Along the contact of limestone and monzonite south and southeast of Mammoth there is a great deal of surface oxidation, and the limestone contains irregular bodies of limonite, kaolin, and jasperoid. Some such small deposits are found near the Black Jack shaft, but the largest mass is on the property of the Dragon Consolidated Mining Co., usually termed the Dragon iron mine.

The mine, which is described in part in connection with the Iron Blossom ore channel (p. 245), lies along the railroad track 2¼ miles east-southeast of Mammoth, at an altitude of 6,800 feet. At the surface the mine is an open pit about 200 by 75 feet. Tower and Smith state that it was being worked in 1897 as an open cut 200 feet deep, the ore being loaded on teams and hauled out of the open cut to the surface through large tunnels. In 1911 the

pit was really deeper, in part, for on the 300-foot level of the shaft a drift opens to daylight into the pit. A vertical shaft has been sunk since 1897 to a depth of 1,065 feet for the development of both iron-ore and vein deposits of the property.

The country rocks are altered latite and monzonite porphyries and metamorphic limestone, including the Ajax and Opohonga. The limestone surface pitches steeply southward beneath the bleached, altered porphyry. No certainly intrusive contact at or near the surface is known east of the northward-trending monzonite contact that lies 750 feet west of the shaft.

The eastward-trending contact of limestone and monzonite, which is here difficult to trace, appears to extend directly across the pit. It dips southward and goes below the 300-foot level, though the shaft passes into the limestone, which continues downward. A vertical drill hole that extends 996 feet from the bottom of the shaft is almost wholly in limestone, passing into monzonite 6 feet from its bottom. Another vertical drill hole 726 feet deep in the gulch east of the Brooklyn shaft passes through the porphyry into limestone that is cut by three apophyses of monzonite porphyry. A horizontal drill hole on the 600-foot level has proved altered limestone to extend at least as far as a point 540 feet east and 225 feet south from the shaft. Another hole on the 600-foot level has proved it to extend at least as far as a point 590 feet east and 500 feet south from the shaft. East and south drifts on the 800 and 1,000 foot levels pass out of the altered limestone into monzonite identical with that of the main stock.

The great body of iron ore occurs in shoots which are of irregular shape but whose largest dimensions run approximately east or north. They stand nearly vertical and are completely surrounded by a mass of hard kaolin (locally called "talc") which may contain considerable free silica. The boundaries of the shoots are marked by minute branching cracks stained with brown iron oxide, which penetrate for a short distance into kaolin, and by specks or small spots of the oxide, which impregnate the kaolin.

The ore body of the pit is said to end just below the 300-foot level. On the 400-foot level was encountered another body of iron ore which appears to be a flat mass, ending a short distance below that level. The iron ore of both bodies is a compact limonite (perhaps with some hematite) with 55 to 57 per cent iron and 4.5 per cent silica.

Much of the ore contains a trace of gold; the silver content is irregular, at most 2 ounces to the ton. Copper stains are rarely observed. Pharmacosiderite, an arsenate of iron, may be seen in places, but the quantity is insignificant.

The ore bodies are surrounded by white masses of kaolin, which gradually becomes ferruginous and silicified and finally passes into limonite and jasperoid. The surveyors of the company state that the ore body is not magnetic, and the surrounding limestone certainly contains no magnetite other than a few microscopic grains.

Tower and Smith observed that the ore bodies in the pit stand nearly vertical and follow both northerly and easterly fissures, but from present exposures their attitude seemed difficult to ascertain with certainty. The same authors state that in the pit were also found isolated masses of copper-lead ore rich in silver, with a quartz and barite gangue. This statement confirms the observation that the Dragon vein crosses the open pit, and as these ore masses "are almost invariably found in the plane of projection of this vein" a justified conclusion is that they are simply parts of this vein which have later been surrounded by limonite.

"The limonite [of the pit] is either in cavernous masses, having horizontally banded botryoidal structure or in dustlike particles through the jasperoid."[1]

An analysis of the iron ore by George Steiger[2] runs as follows:

Analysis of ore from Dragon iron mine.

SiO_2	3.25	TiO_2	None.
Al_2O_3	.76	H_2O 100−	1.71
Fe_2O_3	80.02	H_2O 100+	12.30
FeO	.24	SO_3	.47
CaO	.42	S	.10
MgO	.30	P_2O_5	.78
CuO	None.		
BaO	None.		100.35
MnO	Trace.		

Under the assumption that the impurities exist as free silica, silicates, phosphates, and sulphates, recalculation indicates an iron hydroxide composed of 86.6 per cent Fe_2O_3 and

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 766.
[2] Idem, p. 767.

13 per cent H_2O. Pure limonite contains 85.5 per cent Fe_2O_3 and 14.5 per cent H_2O. Considering that a small part of the ferric oxide is almost certainly combined with silica and sulphuric acid, there is small probability of the presence of hematite, turgite, or goethite in the material represented by this analysis.

The N. 72° E. drift on the 175-foot level, starting just north of the shaft, passes through white or nearly white kaolin to a point about 140 feet from the large open cut. Here it passes through a zone full of stringers and patches of iron ore, which gradually gives way to a body of iron ore, with a minor amount of black manganese ore and a few large inclusions of kaolin. The iron ore is continuous to the bottom of the open cut. Similar large inclusions of kaolin are exposed in the north and northeast walls of the open cut, and their exposed long dimensions as a rule are vertical. The north crosscut from the N. 72° E. drift passes through kaolin for most of the distance but also cuts a large block of impure crystalline dolomite that closely resembles the metamorphic portion of the Opohonga limestone. It is bounded on the north by kaolin strongly impregnated with black manganese oxide (wad), and on the south, along a joint plane, by a mixture of kaolin and the iron and manganese oxides. The iron and manganese show a tendency to concentrate between the dolomite and kaolin. The dolomite block is brecciated in places, and cracks near its edges in the roof of the drift are streaked with the iron and manganese oxides.

Kaolin seams in iron ore on the 400-foot level are said to be parallel to the bedding. A similar structure is exposed on the surface in a railroad cut just northeast of the open cut—that is, near the edge of the iron-bearing ground—where certain beds of crystalline dolomite or limestone are partly replaced by brown iron ore. On the 600-foot level a horizontal drill hole has proved iron ore and kaolin in more or less altered limestone (or dolomite?) to extend southward for at least 125 feet from a point 540 feet east of the shaft. Another drill hole on the same level has passed through seams of iron-stained kaolin from a point 330 feet south and 230 feet east to a point 500 feet south and 590 feet east from the shaft. The rock containing the kaolin is altered limestone which in places carries much pyrite. These drill records appear to mark the lower extremity of the ore body, which seems as a whole to follow the limestone contact beneath the porphyry.

On the 800 and 1,000 foot levels the limestone is for the most part coarsely crystallized without metamorphic silicates or spinel. The dips are low to the east, as shown on the maps, and as a whole are uniform. The original characters by which limestones were distinguished on the surface are all obliterated by metamorphism. According to a calculation of thickness the limestones of these two levels should both be in the Cole Canyon dolomite, although certain specimens collected on these levels have a relatively high calcium contact.

The contacts between limestone and igneous rock on these levels are all intrusive, and the igneous rock is monzonite of the type in the main stock, none of the possibly effusive types shown on the surface to the south and east of the Dragon shaft being represented. The contacts to the west end of the 800-foot level, including the south crosscut from the west end, are sharp and nearly vertical. The monzonite is somewhat impregnated with pyrite and contains considerable sericite accompanied by calcite and silica in microscopic grains. The contact in the south drift of the 800-foot level is a complex of monzonite apophyses and metamorphic limestone inclusions for a distance of over 100 feet. Monzonite was struck on the 1,000-foot level southeast of the shaft, as shown on the maps, one or two days after the visit in 1914. The contact is sharp and showed little evidence of kaolin and limonite. The monzonite contains some disseminated pyrite.

An interesting feature is the discovery of smaller masses of kaolin and limonite in west drifts on the 800-foot and 1,025-foot levels in the vicinity of the Brooklyn shaft, where bodies of the same minerals also appear on the surface. These bodies are still above the water level. This material is of the same character as the general run in the Dragon iron mine. It replaces the marbleized limestone, and the smaller exposures lie along distinct fracture lines.

The Huntington tunnel, a short distance east of the James tunnel, extends for 45 feet through altered monzonite porphyry and then passes across a nearly vertical contact into white kaolin, which for a few inches from the

contact is specked with brown iron oxide. A specimen of the kaolin from the contact gave, on drying, a small efflorescence of soluble white salt with the taste of alum. The kaolin continues to the end of the tunnel, at one place cutting across the bottom of a limonite body (fig. 47), which pinches downward about halfway from the roof to the floor of the tunnel. Irregular fractures, branching and crisscrossing in all directions around the limonite, are

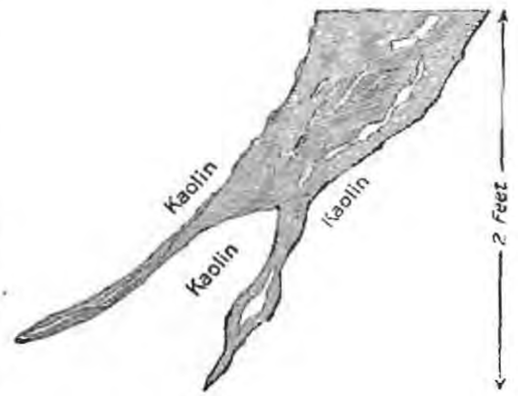


FIGURE 47.—Stringers of limonite replacing kaolin, Huntington tunnel.

stained with the iron and manganese oxides which spread from the fractures into the kaolin. A few remnants of unreplaced kaolin still remain surrounded by iron ore, duplicating on a small scale the inclosed kaolin masses in the large open cut.

BLACK JACK IRON MINE.

The Black Jack iron mine, owned by the Black Jack Consolidated Mining Co., lies in metamorphic limestone about 500 feet due north of Diamond Pass, along the north end of an altered northerly dike extending from the monzonite mass. The ore is of the same character as that of the Dragon iron mine and is mined mostly by open cut. A tunnel from the road west of the dike, 100 feet below the open cut, also penetrates iron ore; but the deposit pinches out within the next 100 feet downward, as the 200-foot level from the Black Jack shaft, cut to prospect the iron-ore body, failed to find either iron ore or quartz, thus proving that the iron ore is a superficial deposit and not the gossan of a siliceous vein deposit. The open cut lies along the east wall of the dike. The dike is altered along the wall of the open cut to a kaolinized mass, which gradually changes into the ore. On the surface, at the top of the iron-ore outcrop, is a breccia composed of silicified limestone fragments in an iron-stained matrix.

At one of the small prospects about 450 feet up the slope east of the open cut a bed of the silicified rock forms a cap over a body of yellow to red low-grade soft iron ore. This ore, a mixture of iron oxide and white kaolin, is replacing metamorphic limestone and has in places preserved the structure of the original rock. The metamorphic limestone below the deposit and southward to the monzonite contact is the brown-weathering pyroxene-spinel rock crisscrossed by veinlets of white calcite. A thin section of this rock shows it to consist of enstatite, more or less completely replaced by serpentine and a little calcite, and green spinel, replaced by brown iron oxide and kaolin. A little garnet, magnetite, and probably pyrite are also present, more or less replaced by brown iron oxide. The weathered surface of the rock is well sprinkled with iron-oxide specks, which must represent for the most part spinel and also the garnet, magnetite, and pyrite. The total iron present, however, is small and could scarcely account for even the small Black Jack deposit, not to mention the great Dragon deposit, without a vast amount of concentration.

OTHER OCCURRENCES OF IRON ORE IN THE TINTIC DISTRICT.

Other iron and manganese deposits of the Dragon type have been worked at the Iron King mine, and small deposits have been found in the East Tintic Development Co.'s mine, in the Tintic Standard mine, and on a claim of the Chief Consolidated Mining Co. near Homansville.

The Iron King mine is over half a mile east of the Colorado mine. The immediate wall rock is the Bluebell dolomite, which slopes southward beneath the bleached silicified early rhyolite. A little float marks the former presence of the Packard rhyolite, which once overlay the site of the mine. No intrusive rocks were recognized, although a few dikes may be present and concealed by the general bleaching.

The occurrence in the Tintic Standard workings is along the northwest drift on the 400-foot level. The inclosing rock is dark-bluish limestone. The iron-manganese-kaolin de-

posit, of the Dragon type, lies along a northwesterly break. Here, as at the Iron King mine, the limestone was once overlain by the Packard rhyolite, but in this locality the nearest rhyolite outcrops show no widespread bleaching. The only surface indications of mineralization in the vicinity of the property are a few outcrops of silicified limestone.

The East Tintic Development Co.'s works have exposed a similar deposit on the 330 and 500 foot levels.

According to the earlier report [1] iron ore of the same kind occurs in the Sacramento workings, in lower Cole Canyon, but no description is given, and the mine is now idle. The same report also mentioned the iron ore of the Emerald property in this connection. (See p. 203.)

The Chief Consolidated Mining Co. in 1916 and 1917 made a few shipments aggregating 897 long tons from a newly opened manganese deposit near Homansville. The ore contained from 38 to 42 per cent of manganese, 0.5 to 1.5 per cent of iron, and 7 to 12 per cent of silica.

GENESIS OF THE LIMONITE DEPOSITS.

The question of the origin of the limonite deposits described above is at first glance puzzling. Several hypotheses might be considered. The deposits are assuredly not residual, caused by the weathering of limestone, for the erosion has been vigorous and the bare calcareous rock is everywhere exposed. They are not caused by the weathering and oxidation in place of large pyritic bodies connected with the veins, for the veins apparently pass through the iron deposits and are not difficult to recognize. The deposits are not oxidized contact-metamorphic ores, for although the Dragon iron mine is on or close to the contact there is no evidence in the adjoining limestone of anything more in the way of contact metamorphism than a coarsening of the grain or the development of enstatite and spinel, neither of which yields a noteworthy amount of iron on weathering. The contact of monzonite and limestone has evidently something to do with the deposits, but a different explanation from those mentioned above must be adopted.

The accessible portions of the iron mines are almost wholly in rock so thoroughly decomposed or replaced by iron ore and kaolin that there is no opportunity to see the relations of the ore to the surrounding rock. Deposition by ascending waters was the view favored by Tower and Smith,[2] who suggested that iron leached from the bleached igneous rocks had migrated downward and risen again in thermal springs that reached the surface along the limestone contact and deposited the iron in the form of limonite. They further stated that the structure of the ore, together with the fact that it was limonite, showed that the deposit was made comparatively near the surface by thermal springs; but deeper workings made since their report was written have penetrated beneath the ore and found bodies of it to pinch out downward and to be underlain by altered limestone, impregnated in places by pyrite and cut by seams of iron-stained kaolin. They also suggested that the iron ore was possibly derived from the oxidation of pyrite, as indicated by the sulphur recorded in the analysis, but no evidence favoring the existence of so great a deposit of pyrite has been found.

The limestone in the vicinity of the Dragon and Black Jack deposits is made crystalline by contact metamorphism, but that near the others is not. Only at the Black Jack deposit are contact-metamorphic minerals present. In the lower levels of the Dragon mine some of the limestone, however, contains sparsely disseminated pyrite.

The field relations show with considerable certainty that the limestone is replaced by kaolin and limonite and that possibly in part kaolin is replaced by limonite. A thin section of an altered limestone near the iron ore on the 400-foot level of the Dragon iron mine shows clear evidence of the replacement of calcite by kaolin.

The igneous rocks also vary in composition and structure. That at the Black Jack is an altered monzonite porphyry dike; that at the surface of the Dragon is mostly altered latite or monzonite porphyry of probable effusive origin, which in the lower levels is replaced by intrusive monzonite; that at the Iron King is altered earlier rhyolite partly covered by a little Packard rhyolite, both effusive. At the other minor deposits the igneous rock is effusive Packard rhyolite, not highly altered.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 689.

[2] Idem, pp. 663, 690, 722.

In the discussion of the igneous rocks (p. 65) it was shown that the effusive latites erupted from the Sunrise Peak neck and perhaps from a vent over the present monzonite stock must originally have stood at a much higher level than now, completely covering the limestone areas, and that a possible maximum thickness of 3,000 feet had been eroded from the volcanic centers. The present main area and small outliers of the Packard rhyolite show that it, too, once formed a continuous cover, which, because it has lain in a lower position than the latite and andesite series, has suffered relatively little erosion. The one original structural relation, therefore, common to all the iron deposits is that of a body of dolomite or limestone, altered or unaltered, overlain by volcanic rocks.

During the period of vein formation the ore-forming solutions ascended through the limestone into the volcanic rock along certain main fissure zones, spread along minor fractures, and impregnated the rock for a great distance from the fissures, altering it to a quartz-sericite-pyrite aggregate. This impregnation of the overlying volcanic rocks is shown reasonably well just south of the Dragon open cut, in the bleached outcrops which have been proved by mining and drilling to overlie the limestone and occupy a considerable area. The bleached character of the volcanic rocks is also continuous over an area extending for half a mile northeastward from the Iron Blossom mine to the Iron King, where these clearly effusive rocks overlie limestone.

In all the places cited the altered volcanic rocks contain either disseminated pyrite or small cubic and irregular cavities marking its former presence, and, as indicated above, much of the volcanic rock had been removed by erosion.

The monzonite porphyry adjoining the contact at the Dragon iron mine is a bleached light-gray or yellowish soft and earthy rock, but the grain of the porphyry and the dull-white feldspar crystals are clearly to be recognized. Good examples of this rock are found in the new railroad cuts near the mine.

Tower and Smith noted the alteration, described the rock, gave an analysis of it, compared it with the fresh monzonite, and found that silica was greatly increased, while lime, iron oxides, and soda were largely removed. Potash, on the other hand, had been somewhat increased and the water above 100° more than doubled. The rock contained no sulphides and no carbonates, but 0.25 per cent of sulphuric anhydride present in a sulphate. These authors noted that a great removal of iron had taken place. The fresh monzonite contained 7.07 per cent of $Fe_2O_3 + FeO$, and the altered rock only 1.10 per cent. They justly attributed the alteration of the rock to hydrothermal action, concluded that the "universal removal of iron from the igneous rocks in the vicinity of these deposits indicates a possible source of their iron,"[1] and held that the deposits were made near the surface by thermal springs either as limonite or perhaps as pyrite.

Tower and Smith[2] presented the following analysis of the altered and bleached "monzonite":

Analysis of altered "monzonite" near Dragon mine.

[H. N. Stokes, analyst.]

SiO_2	71.14	Na_2O	0.07
TiO_2	.75	Li_2O	Trace.
Al_2O_3	16.24	H_2O at 110° C.	.49
Fe_2O_3	.94	H_2O above 110° C.	2.74
FeO	.16	P_2O_5	.32
MnO	Trace.	V_2O_3	.02
CaO	.25	CO_2	None.
SrO	Trace.	SO_3	.26
BaO	.05		
MgO	1.12		99.51
K_2O	4.96		

This analysis shows conditions characteristic of rock alteration by hydrothermal processes. The leaching of sodium, calcium, and magnesium, the silicification and the concentration of potassium are characteristic. The rock contains roughly 50 per cent of sericite and 50 per cent of quartz.

The absence of pyrite and the strong leaching of iron are, however, unusual features. In an alteration process of this kind in a heavily mineralized district the solutions almost always contain hydrogen sulphide which would convert the iron in the silicates to pyrite. The looseness of the material and its proximity to the surface in a region of deep oxidation justify the inference that the hydrothermally altered rock has been leached by oxidizing solutions which removed the pyrite but were unable to affect other constituents to a great extent.

[1] Tower, G. W., jr., and Smith, G. O., op. cit., p. 722.

[2] Idem, p. 661.

After exposure at the surface these pyritic volcanic rocks were oxidized by surface waters. The pyrite oxidized to iron sulphate (ferrous, ferric, or both), setting free sulphuric acid, which reacted with sericite and converted it in part to soluble alum and soluble silica, leaving a residue of insoluble kaolin and unattacked quartz. The ferric sulphate in part oxidized to limonite and was in part carried slowly downward with ferrous sulphate, alum, and any unused sulphuric acid; or, in the presence of a sufficient supply of oxygen, all the iron sulphates may have become converted into limonite, with a corresponding renewal of sulphuric acid. To a minor extent arsenates and phosphates were formed. The small amount of silver in the pyritic igneous rock was oxidized to sulphate and precipitated by waters containing chlorine as cerargyrite. The minute amount of gold became dissolved in chlorine generated by manganese, sulphuric acid, and sodium chloride in the water and participated in the downward migration.

The slow advance of this process of migration downward to the contact with the underlying limestone would thus bring an increasing supply of sulphuric acid, aluminum sulphate, silica, and iron sulphate in solution. The finely divided kaolin and newly precipitated iron oxide may also have been to some extent carried downward in suspension by water percolating through the porous residual mass.

In the underlying limestone or dolomite the calcium and magnesium carbonates were in part dissolved by sulphuric acid and removed in solution, leaving only a small residue of kaolin, and in part they were replaced by kaolin; interaction between iron sulphate and calcite also produced a precipitate of limonite. The final result of the process would be in part the metasomatic replacement of the limestone or dolomite by limonite or kaolin or both. The total amount of iron ore and kaolin thus formed would depend upon the thickness of the overlying volcanic rock and its percentage of pyrite.

The sulphuric acid and sulphates involved in this explanation would have no appreciable solvent action upon the vein quartz and barite which are present in the Dragon iron mine and distinctly older than the iron ore.

After the country rock was replaced, there was evidently a tendency for the newly formed kaolin to be itself replaced by iron oxide, presumably by a reaction with any iron sulphate still available or by a simultaneous oxidation of iron sulphate and solution of kaolin by the resulting sulphuric acid. By this process the iron ore and kaolin tended to concentrate into distinct bodies, the kaolin preceding the iron ore downward and laterally, or away from the main sources of supply. The manganese ore was formed by reactions of the same kind as the iron ore; but owing to its greater solubility it also tended to precede the iron ore downward, and in the great Dragon deposit it forms small bodies outside of the large bodies of iron ore. The manganese ore also has evidently been concentrated by the replacement of kaolin.

The accumulation of ore would naturally be greatest where the amount of pyritization was greatest—that is, near the principal vein zones. The downward migration of materials would tend to localize along the more persistent open fissures and in shattered rock along the intersections or junctions of different fissures, thus concentrating the ore into bodies which, though irregular in detail, stand in generally vertical positions parallel to the directions of fissures in the adjacent areas. As the water level stands much higher in the monzonite and porphyry than in the limestone the flow of solutions would be mainly in the direction of the contact.

It is impossible to give more than a rough estimate of the volume of volcanic rock that must have been leached to supply the limonite in the iron-ore bodies. The total amount of ore, already mined and in reserve, has been estimated by L. E. Riter,[1] the manager of the mine in 1911, to be between 750,000 and 1,000,000 tons. The pyritized volcanic rock may be reasonably assumed to have had an average specific gravity of 2.70 (the mean between quartz and sericite), not allowing for pore space, which would imply a weight of 168.75 pounds to the cubic foot. If pyrite[2]

[1] Letter to G. F. Loughlin.

[2] The omission of pyrite in estimating the assumed specific gravity will tend to compensate any overestimate of sericite. If the pyritized rock consists of 50 per cent silica (volumetric) with a specific gravity of 2.63, 45 per cent sericite with a specific gravity of 2.75, and 5 per cent pyrite with a specific gravity of 5.0, the specific gravity of the rock would be 2.80 instead of 2.70, and the available quantity of pyrite correspondingly greater.

is assumed to average 5 per cent of the rock, as in the drill samples mentioned on page 154, 1 cubic foot of the rock will contain 8.4 pounds of pyrite, equivalent to 6.5 pounds of limonite. A block of pyritized porphyry 100 feet square and 1,000 feet high, containing 10,000,000 cubic feet, could thus account for about 29,018 long tons of limonite, or from 2.9 to 4 per cent of the total estimated quantity. A block 1,000 feet long, 1,000 feet high, and 250 feet wide could furnish all the minimum or three-fourths of the maximum estimated quantity of ore.

There are, of course, many uncertainties in this rough estimate: The average content of pyrite may have been more or less than 5 per cent; pyritization may have extended less or much more than 1,000 feet above the present surface; not all the iron derived from a given volume of the eroded porphyry was concentrated into this one limonite body; pyritized zones in the limestone, now replaced by the ore, must have added materially to the available supply of pyrite. There seems to be no reasonable doubt, however, that there was enough pyrite in the former overlying rocks of the vicinity to supply all the limonite, even for the largest of the iron deposits.

The accumulation of the iron ore is doubtless still going on, as shown in the Huntington tunnel (p. 261), where kaolin is being impregnated by limonite derived from oxidizing pyrite in the adjacent porphyry, and alum is being formed. The present mass of pyritized porphyry from the lower levels, according to the drill cores obtained beneath Dragon Canyon (p. 154), has not undergone much oxidation as a whole, but considerable oxidation has taken place along fissures, as shown by the oxidized ore developed in veins down to water level—a depth of 400 to more than 650 feet in different places. Where these fissures reach the limestone the formation of iron ore and kaolin should be going on, beginning new deposits or augmenting the lowest portions of the great Dragon deposits, which have migrated downward along the contact beneath the porphyry at least as far as the 600-foot level. Bodies of iron ore may be found as far down as the water level, but any below the great body should be expected to be small and to become smaller with depth. There may, however, be some concentration of copper beneath the main deposit, if the eroded part of the porphyry contained an appreciable amount of copper. The drill core in Dragon Canyon (p. 154) shows that some of the pyritic monzonite contains as much as 0.5 per cent of copper.

NORTH TINTIC DISTRICT.

By G. F. Loughlin.

TOPOGRAPHY.

The North Tintic district includes all the country in the East Tintic Range north of the Tintic and East Tintic districts. It is divided topographically into three nearly parallel mountain ranges of northerly trend. The western and central ranges are forks of the main East Tintic Range, which splits just beyond the northwest corner of the Tintic quadrangle, and are separated by a prominent valley known as Broad Canyon. They are characterized by somewhat opposite symmetry. The western range has a sinuous divide with several rounded peaks, a short and steep though irregular eastern slope, and a western slope composed of long spurs that extend westward for about 3 miles with very gently sloping crests and end abruptly along the east edge of Rush Valley. It terminates on the north in a cluster of foothills which are separated from the south end of the Oquirrh Mountains by the narrow pass which connects Rush and Cedar valleys. The central range has a straighter and more regular divide, a steep, more regular western slope, and moderately sloping eastern spurs that terminate along the west edge of Cedar Valley, a broad, flat closed basin, partly covered by dry farms. The eastern or southeastern range extends north-northeastward from Pinyon Peak, forming the southeast boundary of Cedar Valley, and is practically continuous with the Lake Mountains, which separate Cedar and Utah Lake valleys.

There are no towns or villages in the North Tintic district, owing to the scattered distribution of the mines. Water is obtained in the western part of the district from wells driven in the alluvium of Rush Valley; in the central and eastern parts from springs, the largest of which is Greeley Spring, at the south end of Cedar Valley.

GEOLOGY AND ORE DEPOSITS.

WESTERN RANGE.

GEOLOGY.

Only a hasty reconnaissance of the geology of the district has been made. The western range coincides with the principal anticline of the

region, the anticlinal axis passing north-northeastward through the northwest corner of the Tintic quadrangle and pitching northward beneath Broad Canyon. The same sequence of strata is represented on the west limb as on the east, save for the presence of a prominent bed of quartzite which lies at the approximate horizon of the Herkimer limestone in the west fork of Broad Canyon, near the Hot Stuff prospect. This quartzite bed has not been carefully traced but appears to have pinched out eastward, as it was not seen in corresponding position on the east limb of the anticline near the head of the east fork of Broad Canyon. There is said to be an outcrop of quartzite farther north along the crest of the central range, but it has not been visited by the writer. Such a bed should correspond closely in stratigraphic position with the quartzite at the Hot Stuff property. It is not likely that this quartzite is an upfaulted part of the Tintic quartzite, as there is no repetition of shale and limestone (Ophir and Teutonic formations) above it; on the other hand, these two and the Dagmar limestone lie below it, and poor exposures of the Herkimer limestone and Bluebird dolomite followed by good exposures of the Cole Canyon dolomite and still higher strata lie above it.

The members above the Cole Canyon dolomite, including the Opohonga limestone, form the divide that separates Broad Canyon from Rush Valley. The Opohonga limestone is the most conspicuously exposed formation along the Eureka-Scranton trail and forms the summits of all the peaks from the head of Black Rock Canyon to the head of the north fork of Barlow Canyon. It has not been followed north or south of these places.

West of the divide the Ordovician and Mississippian strata of the Tintic section lie across the long westward-sloping ridges between the wide canyons (Miner's, Black Rock, Barlow, and others) that enter Rush Valley. They strike for the most part north-northeast and dip 20°-30° W., but a mile north of the Scranton mine they curve eastward and cross the northward-pitching anticlinal axis. The lower northern hills of the range are, so far as seen, composed wholly of the Humbug formation, which there as a whole dips gently northward but is marked by several undulations. The Humbug also forms the west face of the range southward to Miner's Canyon and beyond, possibly as far south as the low hills that extend westward and separate Tintic and Rush valleys. Southeast of these low hills the front of the main range turns abruptly eastward, cutting across the different limestone formations and the west limb of the Tintic quartzite. The topography of the range front here strongly suggests fault scraps, or typical Basin Range structure.

Igneous rocks in the western part of the North Tintic district are limited, so far as known, to two dikes or sills of monzonite porphyry and a few remnants of surface flows. Specimens from the dikes have been shown to the writer, but neither dike has been seen in place. A patch of dark, weathered latite was found half a mile northeast of the Eagle Eye prospect, on the lower west slope of Broad Canyon. A rhyolite patch was found in the head of the east fork of Broad Canyon, south of the Wasa prospect, and other small areas were seen farther to the southeast; one of these small areas is partly shown on Plate I (in pocket) crossing the north boundary of the Tintic quadrangle, northwest of Fremont Canyon.

The fissuring and faulting that are characteristic of the Tintic district persist northward, and faults of considerable offset may be seen even on a brief reconnaissance trip; but no attempt has been made to trace any of them. Of the two mines that have shipped ore, the Scranton and the New Bullion (Balhinch), the ore bodies of the former are associated with northerly to N. 15° E. fissures and oblique cross fissures, and those of the latter with northerly and easterly fissures.

ORE DEPOSITS.

The ore bodies thus far worked in the western part of the North Tintic district resemble those of the Colorado channel or north half of the Iron Blossom zone and neighboring mines in the Godiva zone more or less closely in form and mineralization but differ from most of them in their extremely low content of silver and silica, and in these respects they recall the upper workings of the East Tintic Development Co.'s mine. The deposits studied are so thoroughly oxidized that data bearing on the genesis of the ore are rather unsatisfactory. From the evidence at hand the ore-forming solutions appear to have ascended along

northerly fissures, branched along certain cross fissures (east, southeast, and northeast), and spread more or less extensively along easily replaceable beds of limestone. Deposition along or near the trunk fissures has given a siliceous lead or lead-zinc ore, and at greater distances from the fissure a lead-zinc ore with a dolomite-calcite gangue. The dolomite forms white granular aggregates and, where open space affords, small curved rhombohedrons. The calcite is present in two forms—narrow pointed crystals (scalenohedrons) the largest an inch or more in length, which mark either the closing stages of primary ore deposition or deposition from primary solutions at some distance from ore bodies, and flat rhombs or scaly crystals, which are the result of secondary changes in the ore and whose formation accompanied or closely followed the deposition of the secondary ore minerals. Descending waters have oxidized the original lead and zinc sulphides and concentrated the metals, especially the zinc, downward along both bedding planes and fissures. In some places a mixture of calcite and the hydrous oxides of iron and manganese has been left to mark the original position of the ore body. The zinc has moved as a rule faster than the lead, and this has given rise in some places to separate though adjacent bodies of lead ore and zinc ore; but in other places the migration has been less and both metals occur together. The cause of this difference in mode of occurrence is concealed by the completeness of oxidation, but it is believed that the separate shoots of lead ore and zinc ore were derived from practically solid mixed sulphide bodies, the zinc content descending and replacing the limestone walls, whereas the mixed lead-zinc ore was derived from sulphides thickly disseminated in limestone, the calcium carbonate reacting with the oxidized zinc solutions and causing precipitation practically in place. These features are all illustrated in the description of the Scranton mines.

SCRANTON MINES.

GENERAL FEATURES.

The Scranton mines, owned by the Scranton Mining & Smelting Co., are on the north and south sides of Barlow Canyon, about 1½ miles from its mouth, about 9 miles northwest of Eureka. (See fig. 48.) They have produced zinc and lead ore. A gasoline compressor formerly furnished power for running two whims, but electric power is now used. Water is hauled from the company's well in Rush Valley, 4 miles away. The ore, after sorting, is hauled by wagon (6 tons to a 4-horse team) 4 miles down an easy grade to the Los Angeles & Salt Lake Railroad at Del Monte station.

The underground workings include four distinct mines—the South Essex Nos. 1 and 2, the Magazine tunnel, and the Del Monte. These lie in a north-south zone which extends across Barlow Canyon for 3,000 feet or more. (See Pl. XXXIX.) All are entered by tunnels, and different levels are reached by inclined raises and winzes.

The immediate country rock is the Pine Canyon limestone, which strikes northeast and dips 25°–45° NW. The dip undulates somewhat, and local variations of horizontal and also of nearly vertical dip are found in a few places, both on the surface and underground. The ore bodies, as in the Iron Blossom zone, have been formed by replacement of a certain member or members of the course-grained limestone. The nearest reported occurrences of igneous rock are two small dikes or sills of monzonite porphyry, one on the same ridge as the Del Monte mine and about a mile west of it, the other in the first small canyon south of Black Rock Canyon, about 2 or 2½ miles southwest of the South Essex workings.

Fissuring and faulting are pronounced in certain places underground but are so concealed beneath float at the surface that the size and directions of the principal faults can be determined only by a detailed study. The most pronounced fissuring underground is along the fault zone known as the "Scranton fissure," a series of breaks, mostly open, which converge at low angles both along strike and dip. Its strike is N. 18°–20° E. and its dip as a rule is vertical to 80° W., with 63° W. in the northern Del Monte workings as the greatest variation from vertical. A few minor branch fissures in this zone have easterly dips. The meager evidence at present available indicates that the "Scranton fissure" was formed after the mineralization, as it cuts off a thin bed of leached mineralized rock in the northern Del Monte workings; but no attempt has been made to determine the amount and exact direction of displacement. Easterly faulting, also later

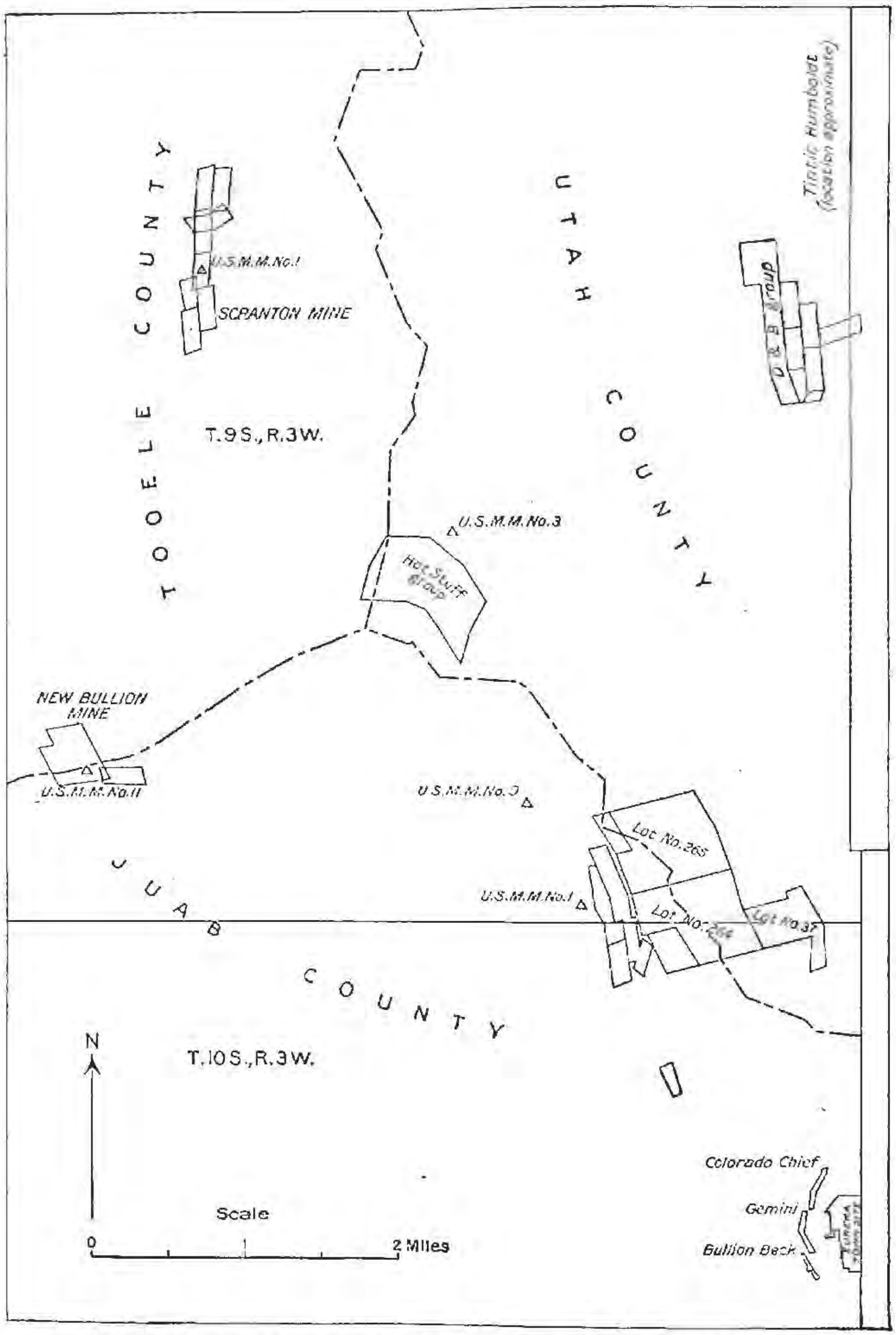


FIGURE 48.—Outline map showing location of Scranton and New Bullion mines, North Tintic district.

than mineralization, may have occurred along the course of Barlow Canyon and along its branch between the portals of South Essex tunnels Nos. 1 and 2, but the apparent offsets in these places may be due to local variations in strike and dip concealed beneath alluvium.

Other fissures, directly connected with the formation of ore bodies, lie in three or four systems; one of these strikes N. 30° E. and dips steeply eastward in the southern Del Monte and other mines, and curves to due north with a 60° W. dip in the middle and northern Del Monte. A second strikes N. 60°–80° E. and dips 70°–80° N. where the first strikes N. 30° E.; and the same or a third system strikes N. 50°–55° E. and dips 70° S. where the first system strikes north. Another system strikes N. 35° W. and dips steeply northwest. As the ore bodies lie along the course of the first of these systems, this system appears to have been the trunk channel along which the ore-forming solutions ascended. The ore bodies, however, are all so thoroughly oxidized and the walls of the stopes and most of the prospecting tunnels are so thoroughly decomposed that evidence is at best obscure. The change in the strike and dip of this system is similar to the changes in strike of the Uncle Sam "west channel" and the East Tintic Development Co.'s vein (pp. 227 and 247), but in this locality the place where the strike changes has not been well exposed and an intersection with a cross break can only be conjectured. Fissures or cross breaks of the other systems appear to have determined the location of some of the ore bodies along favorable limestone beds.

ORE BODIES.

The ore bodies all lie parallel to the bedding, replacing beds of medium to coarse grained, more or less dolomitic limestone. Seven bodies have been worked, besides a few small pockets—two in the South Essex No. 2, one in the Magazine tunnel, and four in the Del Monte mine.

South Essex No. 2.—The two ore bodies in South Essex No. 2 have been worked out. The southern one lies at the intersection of a N. 30° E. fissure and a N. 35° W. fissure, with three nearly parallel N. 70°–80° E. fissures and is only 20 feet or less beneath the surface. Its outline is nearly square save for two branches which extend along the N. 30° E. and N. 35° W. fissures. Its total length in these directions is about 90 feet. The thickness between the N. 70°–80° E. breaks is 10 feet or more; but at the northern of these fissures, a small fault with downthrow on the north, the ore follows in a thin streak down the fault plane for 4 feet and then continues northward along the bedding with a few "gopher holes" where ore has been stoped. The northwest end of the ore body extends down for 20 feet along the N. 35° W. fissure at its junction with a spar-filled fissure, probably of the "Scranton fissure" zone. The ore mined was all sandy lead carbonate with little or no zinc. Toward the southern N. 80° E. break and up the dip of the bedding the ore is bounded by red iron oxide, with some quartz, calcite, and kaolin, which has been followed in a raise to the surface. These same minerals form a more or less continuous cover or "casing" over the ore body and along its sides.

The second ore body, also of sandy lead carbonate, lies a little more than 100 feet farther north, probably on the same limestone bed continued obliquely down the dip. The area of ore is roughly elliptical, measuring 20 by 30 feet, but the "casing" has been followed S. 35° E. beyond it for 45 feet, where the drift cuts the surface on the west slope of a small gulch. About 25 feet west of the stope a little secondary zinc ore with calcite and iron and manganese hydroxides has been found in the Scranton fissure, evidently leached from the ore body. No prospecting west of the Scranton fissure has been attempted at shallow depths, and the possible westward continuation of these ore bodies has not been tested.

South Essex No. 1.—The workings of the South Essex No. 1 lie 115 and 175 feet below those of the South Essex No. 2 but are wholly in or east of the Scranton fissure zone and in the fine-grained blocky limestone that underlies the coarse-grained limestone. The only ore found in South Essex No. 1 was a small bunch of secondary zinc ore in a fissure. Its source can not be determined.

Magazine tunnel.—The Magazine tunnel workings have opened up two beds of mineralized ground. One is a rather low grade deposit formed by the impregnation of a medium-grained dolomitic limestone bed exposed in the upper south drift and along part of an incline that connects the upper drift with the main tunnel level. The ore is only

partly oxidized and in the upper drift consists of galena, dark-brown microcrystalline zinc blende, and lead carbonate, closely associated with dolomite spar and a very little microscopic quartz and pyrite. In one place a small vug was found lined with small twinned calcite scalenohedrons of later growth than the dolomite. In the incline below a large pocket of zinc carbonate and silicate with red iron oxide and flat rhombs of calcite was found along the bedding, and below this on the main tunnel level some secondary zinc ore with iron oxide and calcite was found in a N. 10° E. fissure. This ore body, though not of much commercial importance, has afforded the best

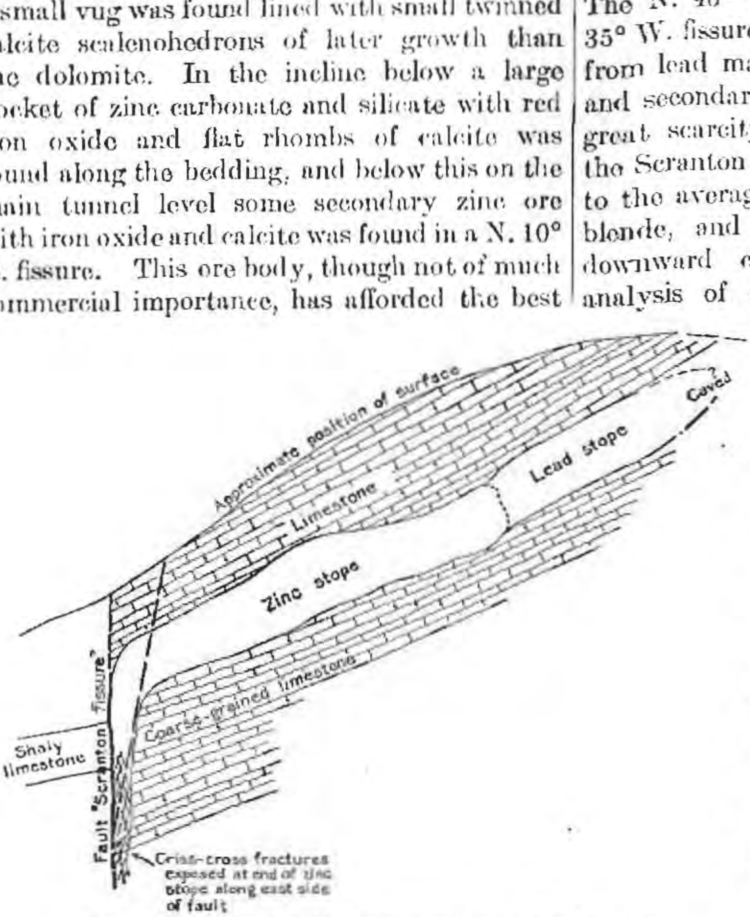


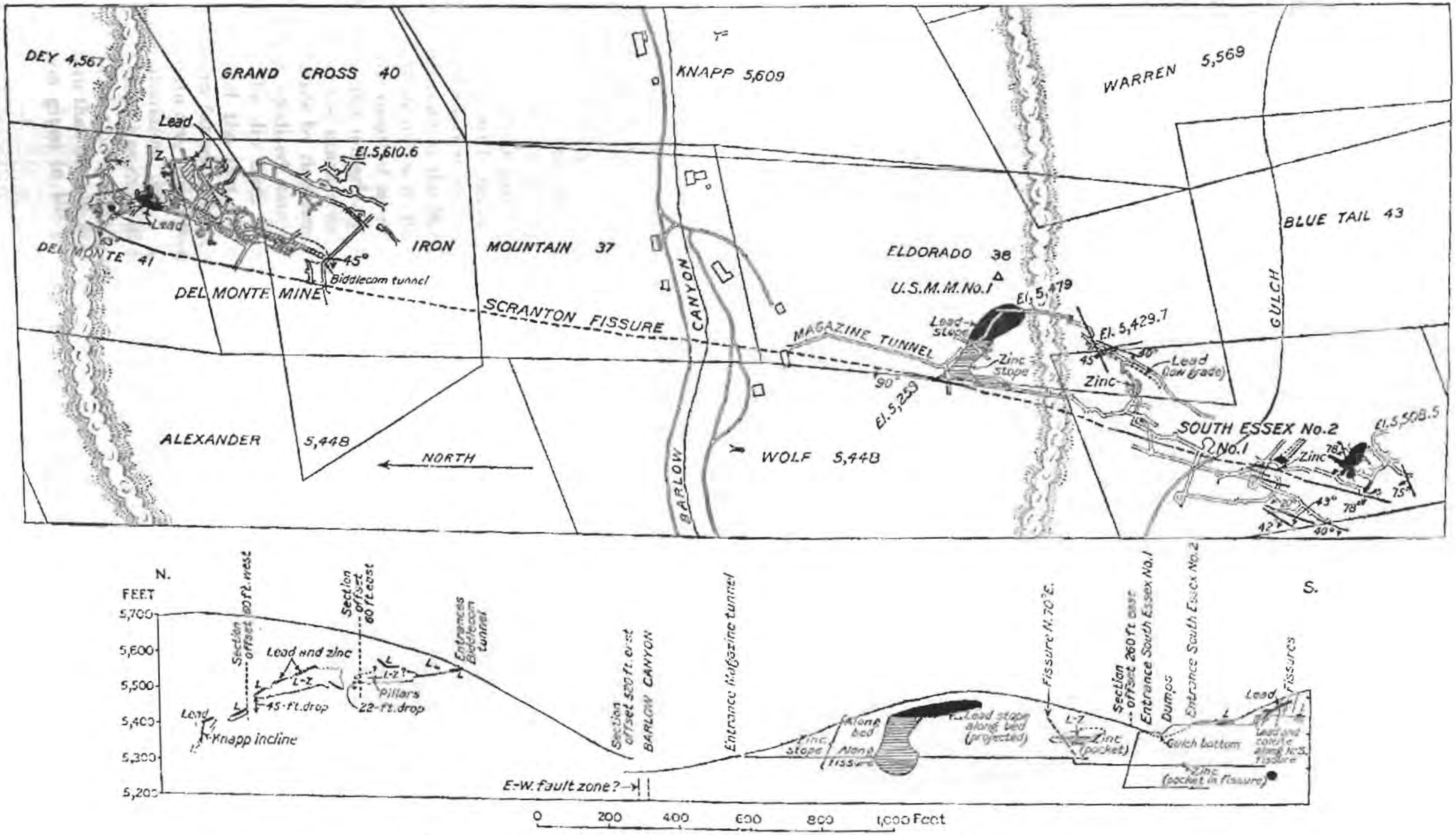
FIGURE 49.—Cross section of Magazine tunnel stopes, Scranton mines.

chance to study the original ore and the relation of zinc to lead.

The second Magazine tunnel ore body, now worked out, lies 130 feet or more stratigraphically above the first. Its upper part (fig. 49) consists of lead carbonate stope 110 feet long, 70 to 80 feet wide, and 10 to 15 feet thick. Its lower part is a zinc-ore stope (carbonate and silicate) 190 feet long, 40 to 140 feet wide, and 6 to 24 feet thick. The whole body extends down the 30° dip of the bedding in a N. 40° W. direction from the uppermost level, near the surface, to the Scranton fissure zone on the main tunnel level, where it turns against a west wall of shaly dense limestone and follows down along the nearly vertical fissure zone for 50 feet. The total vertical height of the ore body is 190 feet, of which the lead stope forms the upper 50 feet and the zinc stope the lower 140 feet. The stopes when visited were inaccessible for close study, but the following features are of interest if considered with the data from the other ore bodies. The N. 40° W. trend nearly parallels the N. 35° W. fissure system. The separation of zinc from lead marks the completion of oxidation and secondary downward concentration. The great scarcity of unoxidized ore throughout the Scranton group prevents any statement as to the average ratio of original galena to zinc blende, and accordingly of the amount of downward concentration. A representative analysis of the zinc ore shipped gives 0.5 ounce of silver to the ton, 2.5 per cent of lead, 14.1 per cent of insoluble matter, 32 per cent of zinc, 0.4 per cent of sulphur, no speiss, and 5.9 per cent of iron. The highest-grade ore shipped carried 52 per cent of zinc. No figures representing the character of the lead ore were obtained.

Del Monte.—The Del Monte mine, the largest of the group, is opened by three tunnels—the Biddlecom, Cole, and Del Monte (Pl. XXXIX)—all of which run northward and are connected by drifts and inclines. To the east of these three is the Grand Cross tunnel, now abandoned, which extends a short distance to an old stope.

Of the three principal tunnels the Biddlecom follows a fissure that strikes N. 45° E. and dips 60° SE., along which two small bodies of lead carbonate have been stoped. These stopes lie on the hanging-wall side of the fissure and are incased in a mixture composed principally of the hydrous oxides of iron and manganese accompanied by calcite. Beyond these stopes the main course of fissuring changes to N. 20° E. Mineralized rock persists, and at one place, about 130 feet from the stopes just mentioned, a small body of lead carbonate with a gangue of quartz (silicified limestone) has been stoped. This body occurs at the junction of two fissures of parallel strike, one dipping 60° W. and one 25°-50° E., and also replaces a limestone bed for a short distance. The replaced bed is faulted for 6 or 7 feet ver-



PLAN AND LONGITUDINAL PROFILE OF ORE BODIES IN SCRANTON MINES.

tically by a third fissure of steep easterly dip, which is itself silicified between the offset portions of the bed.

The Cole tunnel, 150 feet northwest of the Biddlecom tunnel, also starts in an ore outcrop and extends N. 20° E. for 100 feet along the east edge of an irregular bedded stope interrupted by three large pillars and now largely filled with waste. The ore in this stope close by the portal was principally lead carbonate with iron oxide; elsewhere it was a mixture composed chiefly of lead and zinc carbonates, locally known as "combination" ore. The north end of the Cole tunnel stope lies 23 feet above the southwest extremity of the principal mineralized area in the mine, and the intervening ground is heavily stained with iron oxides and closely associated gangue materials.

The principal mineralized area lies north of the Biddlecom and Cole tunnels and is worked from the Del Monte tunnel, whose portal is 80 feet west of the Cole. Mineralization in this area has been proved by a network of drifts to be continuous, and the deposit has been worked in several different stopes. The two easternmost (highest) stopes lie due north of the Biddlecom tunnel. The southern one yields chiefly the "combination" ore, which is bounded on the east by the typical mixture of limonite, psilomelane, and calcite. Downward, along the dip, the "combination" ore is followed by a small body of zinc ore, largely calamine, and directly beneath this is limestone impregnated by a mixture of galena and cerusite and cut by a fracture filled with concentrated cerusite. This reversal of relation, zinc ore below lead ore, which is so marked in the Magazine tunnel as well as in certain mines in the Tintic district, is evidently the result of incomplete downward concentration, the underlying partly oxidized lead ore having lost much of its originally associated zinc blende by downward leaching, and the overlying oxidized zinc ore having migrated down the dip from a higher position. The northern of the two stopes has yielded along its eastern (upper) edge a small amount of lead carbonate ore, which merges down the dip into "combination" ore. A little farther north a third stope has exposed another occurrence of oxidized zinc ore over a galena and cerusite mixture that may be accounted for by the explanation given in the preceding paragraph. This zinc ore may prove to be complementary to the lead carbonate ore just mentioned. Other stopes in this area are of typical combination ore and need no special description. The area, as shown by drifts at the time of visit, was roughly 200 feet square, and the ore stoped ranged from 7 feet down to 1 foot in thickness, forming pinches and swells with no apparent regularity. Two fairly representative analyses of "combination" ore from this area are as follows:

Analyses of "combination" ore from Del Monte tunnel.

Silver	ounce per ton..	0.45	0.50
Lead	per cent..	8.1	2.5
Insoluble matter	do.....	14.9	14.1
Zinc	do.....	33.58	32.00
Sulphur	do.....	.4	.4
Speiss	do.....	.0	.0
Iron	do.....	7.0	5.09

The zinc is said to range as a rule between 20 and 40 per cent; the lead between 2 and 12 per cent.

The next ore body to the north, the Wolf winze stope, begins 45 feet below and 25 feet beyond the northwest limit of the principal ore body. This stope has yielded a lead carbonate ore, high in iron with a gangue of quartz (silicified limestone). Its area is roughly 40 by 60 feet, and it is bounded by two sets of parallel fissures, one trending north and the other N. 40° E. The northerly fissure, which passes along the east boundary, dips 60° W. and bears much the same relation to this body as the N. 20° E. fissures bear to the siliceous lead ore body in the Biddlecom tunnel. Assays of ore from the Wolf winze stope give as a rule from 0.5 to 1.5 ounces of silver to the ton, 21 to 33 per cent of lead, 8 to 24 per cent of silica, 2 to 3 per cent of zinc, and 23 to 32 per cent of iron. The highest assay on record at the time of visit was 43.2 per cent of lead, 35 per cent of silica, and 6 per cent of iron.

The northernmost and deepest stope at the time of visit, that around the Knap incline, lies 50 feet north of the Wolf winze stope and about 25 feet below it. The ore here, too, is siliceous lead carbonate with a silver content as high as 3 ounces to the ton. A few copper stains are also present. The stope as a whole follows the bedding, which here has a northerly dip. It is bounded on the east by a northerly fissure dipping 59° W., which is doubtless the one that extends along the east side of the Wolf

winze stope. East of this fissure is a thin layer of iron oxide and calcite "casing," which extends westward along the bedding for about 40 feet and is cut off by the Scranton fissure.

Genesis of the ore.—Although single details of evidence are not convincing, the evidence as a whole around the two northernmost stopes indicates that the mineralizing solutions were introduced through one or more northerly fissures and deposited the ore along the intersection of these fissures with an easily replaceable limestone bed. Cross fissures, trending N. 40° E., appear in some places to have served as branch channels which permitted a more extensive replacement of the bed, but no constant relations between these cross fissures and the mineralized areas have yet been determined. If the intersection between the main northerly fissure and the replaced limestone bed at the Wolf winze stope is continued upward to the south, it will pass just east of the eastern edge of the principal mineralized area and may therefore be interpreted here too as the trunk fissure supplying the ore-forming solutions, which spread down the dip along the limestone bed, silica being deposited with some galena and zinc blende close by the fissure, and the remainder of the ore minerals with dolomite and calcite replacing the bed at a greater distance. The extreme permeability of the limestone bed in the large mineralized area can not, for lack of definite evidence, be explained. It may have been due to extensive shattering or to an abundance of minor fractures that have since been obliterated by the thorough decomposition of the ground. Absence of siliceous ground within the area tends to disprove the existence of additional northerly trunk fissures, although the shape of the Cole tunnel stope and its alignment with the large area suggest fissuring in a northerly to N. 20° E. direction. The N. 20° E. fissure associated with the siliceous ore body in the Biddlecom tunnel may be a southward continuation of the main northerly fissure or a branch from it.

From the absence of pronounced evidence of silicification in the Magazine tunnel and South Essex ore bodies, it may be concluded that the trunk channel with which these bodies are associated has not been exposed underground. There are, however, outcrops of silicified rock a little south of the South Essex No. 2 which, if continued northward, would pass just east of the ore bodies. These ore bodies lie so close to the surface that any direct connections with this silicified zone are now probably removed by erosion. Silicification took place in two stages, as in the Tintic district.

NORTH SCRANTON PROSPECTS.

The North Scranton property is on a westward-sloping spur about 1½ miles north of the Scranton mines. The country rock is the Pine Canyon limestone, of the same character as at the Scranton mine, consisting of alternating bands of medium to coarse gray limestone and darker fine-grained cherty limestone, which dip gently northward. The workings include a shaft, 100 feet or less deep, sunk near the crest of the ridge, three short tunnels driven in the upper south side, and a long tunnel driven in the north side. A little galena and minute crystals of zinc blende associated with white dolomite spar are present in a bed of medium-grained magnesian limestone along a small fault fissure of N. 17° E. trend which lies close to the shaft collar and has been followed by a tunnel for a short distance. About 300 feet east of the shaft and a little down the slope another short tunnel follows a zone of cemented breccia in a fine-grained sandy (disintegrated) dolomite. A few hard fragments of dolomite and some of the cement in the breccia have a lean sprinkling of galena (and zinc blende?) and white dolomite spar. The long tunnel, which had been driven for a distance of 700 feet in July, 1913, was headed toward a point beneath a small prospect pit, a sample from which was said to have contained a little zinc. The material consists principally of soft red iron oxide and calcite in a fissure that strikes N. 17° E. and dips 80° E.

NEW BULLION MINE.

The New Bullion mine, formerly called the Ballinch, is owned by the New Bullion Mining Co., and lies on the south slope of Miner's (Bullion) Canyon, between 3 and 4 miles east of Doremus station on the Los Angeles & Salt Lake Railroad. The mine had been worked in recent years under the leasing system but was idle when visited by the writer in 1912.

The production has been chiefly lead, with considerable zinc and a little silver. Returns from five assays give a trace to 0.015 ounce of gold and 3.55 to 7.1 ounces of silver to the ton, 20.33 to 40.2 per cent of lead, 7.2 to 9.8

per cent of insoluble matter, 14.5 to 22.8 per cent of zinc, 0.6 to 2.4 per cent of sulphur, no speiss, and 6.5 to 13.45 per cent of iron. A 100-ton shipment in 1911 ran 0.003 ounce of gold and 4.71 ounces of silver to the ton and 28.69 per cent of lead. The zinc percentage was not given but was sufficiently high for penalizing. The ore is oxidized, but small quantities of the original sulphides remain; the gangue contains little quartz, the insoluble matter recorded in the assays probably consisting chiefly of silica from calamine. This character agrees with what was seen in the small worked-out stopes on the tunnel level.

The underground workings are reached through a tunnel that extends for 250 feet S. 80° E. and for about 120 feet S. 80° W. An old shaft started on the hill in the outcrop of the main ore body reaches the tunnel at a depth of 110 feet, where the tunnel turns to a westerly course. A winze about 80 feet west of the bottom of the shaft extends for 200 feet below the tunnel level. A drift on the tunnel level, with short crosscuts, extends for 180 feet north and west of the winze. Drifts have been run from the 100 and 200 foot levels of the winze.

The country rock is Mississippian limestone, striking N. 10° E. and dipping, 30°–35° W., and appears to include parts of the Gardner and Pine Canyon members of the Tintic section. Black cherty beds, characteristic of the Pine Canyon limestone crop out along the slope north and west of the shaft, but the underground workings are in beds of a fine to rather coarse grained dolomitic limestone, which are prominent in the Gardner formation. A few thin beds of quartzite and shale are cut by the main tunnel. Fissuring is pronounced in a general northerly direction and one prominent N. 70° E. fissure is exposed. The main ore body, which was inaccessible at the time of visit, is said to be a pipe extending downward from the shaft collar to a point a little below the tunnel level; its upper part is vertical and its lower part has a distinct northerly pitch. The ore for the most part has been lead or lead-zinc ore, but a concentration of zinc ore is said to have been found along the footwall of the northward-pitching portion. Small amounts of ore have also been found in bunches along northerly fissures on the tunnel level northwest of the winze. These attain 15 or 20 feet in length and 5 to 10 feet in width, but those on the tunnel level (the only ones accessible) have been so thoroughly cleaned out and the surrounding walls are so decomposed that an exact idea of the mode of occurrence can not be gained. These bunches of ore lie north of the N. 70° E. fissure, which is also said to be mineralized. The ore bunches are closely associated with veins and pockets of calcite, which is also present along the outcrop at the old shaft; calcite likewise fills other northerly fissures as much as 100 feet or more away from any known ore occurrence.

Fragments of partly oxidized sulphide ore coated with iron oxide were found on the shaft dump. The sulphides are a fine-grained mixture of galena and zinc blende. The galena is of the fine-grained variety and shows some development of the feathery banding noted in the galena of the Scranton mine. The zinc blende is mostly of the dark-brown fine-grained variety, also found at Scranton. Both sulphides are associated with white granular dolomite spar. The secondary lead and zinc minerals are irregularly scattered through the sulphides and gangue. Small rusty pits among the sulphide grains may mark the former presence of pyrite. A part of the iron may also have been originally present as carbonate isomorphous with the dolomite.

On account of the absence or scarcity of silicification the New Bullion ore contrasts strongly with the ore along the trunk fissures in the Scranton property, and it may be inferred that the tunnel-level ore bodies in the New Bullion are either above the siliceous ore, as in the East Tintic Development Co.'s mine, or else are offshoots from a trunk fissure. On the other hand, the silver content is distinctly higher than in the Scranton ore; but here, as at Scranton, oxidation and possible secondary concentration have destroyed the reliability of the data.

PROPERTY OF TINTIC ZINC CO.

Between the New Bullion on the south and the Scranton on the north there are several small prospects. These have recently been taken over by the Tintic Zinc Co., which has begun a campaign of systematic prospecting. Surface indications include mineralized outcrops and closely related calcite veins, of the

same general character as those on the New Bullion and Scranton ground.

CENTRAL RANGE.

GEOLOGY.

The mountains between Broad Canyon and Cedar Valley lie along the east limb of the North Tintic anticline, which corresponds to the west limb of the Tintic syncline. The strata as a whole have steep to vertical and even slightly overturned dips, save along the foothills at the head of Cedar Valley, where the dip is very irregular and there are several local anticlines and synclines. These local folds evidently mark the approach to the principal synclinal axis, which lies beneath Cedar Valley and is the northward continuation of that in the Tintic district. The structure, however, as thus outlined is complicated by faults of considerable displacement, which follow generally northerly and easterly directions, as well as by numerous other faults formed at different times during and since the folding of the strata. All the strata in the Tintic section are represented here, from the Tintic quartzite, which is present in the upper part of Broad Canyon, through the series of Middle (and Upper?) Cambrian, Ordovician, and Mississippian limestones to the basal beds of the Humbug (upper Mississippian) formation. Patches of rhyolite are scattered along the foothills bordering Cedar Valley.

MINES AND PROSPECTS.

Little or no ore has been produced in this part of the North Tintic district, but several outcrops of promise, both of siliceous and nonsiliceous character, have been prospected to some extent.

The most striking siliceous deposits, of which the Farragut and Deprezin are examples, are the large quartz outcrops along Fremont Canyon, which is virtually a southwest fork of Cedar Valley and heads just north of Packard Peak. Outcrops of quartz or silicified limestone are said to extend northward from Fremont Canyon along the east slope of the mountains, but they were not followed north of the Deprezin shaft.

FARRAGUT.

The Farragut mine, owned by the Admiral Farragut Mining Co., includes a group of 29 claims extending from the northern boundary of the Gemini ground to the south base of the high mountain on the divide between Fremont and Broad canyons, beyond the limits of the Tintic quadrangle. The workings are at the bend in Fremont Canyon at the west edge of the small area of the Humbug formation. (See Pl. I, in pocket.) They include a tunnel with several irregular branches and a shaft 260 feet deep with a 44-foot winze from the bottom level, which are all within the Pine Canyon limestone and are confined mostly to quartz bodies that crop out very prominently. The property was idle when visited in 1912, and only the tunnel was examined. The quartz in the tunnel-level workings ranges from light to dark in color, is more or less leached, and is associated with a ferruginous clay material in decomposing limestone. Assays of the quartz at different places are said to have yielded $1 to $7 a ton in gold, 5 to 25 ounces a ton in silver, as much as 3.5 per cent in copper, and as much as 11 per cent in lead; but no attempt has yet been made to develop or block out bodies of ore. Indications of ore in limestone are said to have been found at the bottom of the shaft.

DEPREZIN.

The Deprezin property, named after the late Capt. H. Deprezin, of Eureka, lies north of the Farragut, near the mouth of a west branch of Fremont Canyon. It consists of six claims. The shaft is beside a conspicuous quartz outcrop that trends N. 10° W., apparently along a nearly vertical fissure, and sends a few branches along the gently eastward or northeastward dipping beds of Pine Canyon limestone. The shaft is about 100 feet deep, and two drifts have been run from the bottom, one for 35 feet westward and one for 145 feet eastward. These workings were not examined but are said to be all in leached quartz. At 15 feet below the surface in the shaft some material assaying 7 per cent of bismuth was found in a shoot dipping northeast. Assays of the quartz thus far have yielded a trace of gold and at most 2 ounces of silver to the ton, but no lead or copper.

TINTIC-HUMBOLT.

The only prospect visited in this section that represents the nonsiliceous type is the Tintic-Humbolt, which is on the lower east slope of the range in a canyon that marks the northern limit of the highest summits.

It is about 7 miles due north of Packard Peak. The immediate country rock is the upper part of the Pine Canyon limestone, which consists of alternating bands of the black cherty and the coarse-grained limestone of the Iron Blossom zone. The dip is vertical to very steep westward (where slightly overturned). Two shafts have been sunk, one 100 feet and one 20 feet deep. Both are in cherty dolomitic limestone. The outcrop at the collar of the 100-foot shaft is of cherty limestone cut by veinlets of white to brownish calcite of columnar to coarse granular character, containing a few small lumps and grains of "steel" and "cube" galena with a little zinc blende. The chert lenses may be mistaken for quartz similar to that of the low-grade siliceous ores in the Tintic district, but it is a significant fact that the ore minerals were found only in the calcite veinlets or the immediately adjacent limestone and not in the chert, also that the chert is equally abundant where there is no evidence whatever of mineralization. The ore minerals were followed for 15 feet down the shaft, and a picked sample is said to have assayed 26 ounces of silver to the ton and 44 per cent of lead. The shaft continues downward along an iron-stained fissure, and a short crosscut from its base is said to pass through 8 feet of kaolin into some siliceous material, full of iron and manganese oxides, which assays traces of gold and silver. Just south of the 100-foot shaft is an easterly fault or cross break, and fractures parallel to it are filled with white and locally yellowish calcite. The facts observed suggest that in this direction mineralization at the surface has nearly reached its northern limit.

SOUTHEASTERN AREA.

GEOLOGY.

The southeastern area includes the range extending north-northeastward from Pinyon Peak and the lower ridges just west of Pinyon Peak. The country rocks are nearly all limestones, cut by a few rhyolite dikes and in part covered by a veneer of effusive rhyolite. The formations exposed range from Cambrian to upper Mississippian Limestone of probable Cambrian age has been noted on a low knob east of Pinyon Peak. The Ordovician is represented by the Ajax and Opohonga limestones and the Bluebell dolomite; the Ajax and Opohonga were noted along the lower eastern slopes of Pinyon Peak, and the Bluebell from Homansville Canyon northward along the upper eastern and northern slopes of Pinyon Peak. The upper part of the strata mapped as Bluebell along Pinyon Peak may include beds of Silurian or Devonian age. Devonian shaly limestone about 150 feet thick—here designated the Pinyon Peak limestone—has been traced along the top of the Bluebell dolomite from the nose of the blunt eastern spur of Pinyon Peak southwestward to the south base of the peak. It is absent on the northern slope of Pinyon Peak and in Homansville Canyon, Mississippian beds resting upon the Bluebell dolomite at both places. The lower Mississippian limestones (Gardner and Pine Canyon) form the western slopes and summits of Pinyon Peak and the lower peak to the south. They have also been noted at different points along the range toward the north and with a few overlying patches of the Humbug formation they form the low ridges to the west.

The area consists for the most part of the east limb of the main syncline of the region, the prevailing dip being about 20° W. The synclinal axis extends along the east side of Fremont Canyon and beneath Cedar Valley. Faulting is conspicuous in places and both northerly and easterly systems are doubtless present, but as in the Tintic district only the easterly faults are clearly expressed on the surface. Fissuring without conspicuous faulting is abundant in the few places where any extensive underground work has been done

PROSPECTS WEST OF PINYON PEAK.

There are only a few small prospects in the ridges west of Pinyon Peak. The Eureka-Comstock, which is at the southwest base of the 6,725-foot peak, has a shaft 50 feet deep, following a narrow vertical silicified zone. The outcrop of the zone is oxidized to a red color. A little gold and silver have been reported. The North Colorado shaft lies just south of the Eureka-Comstock but was not accessible. On the Davis group, to the north, a shaft was being sunk at the time of visit along an 18-inch vein of iron and manganese oxides that assayed a trace of gold.

MINES AND PROSPECTS NORTH AND NORTHEAST OF PINYON PEAK.

Considerable work has been done along the ridge east of Cedar Valley and north of Pinyon Peak, but only three properties, the Lehi-Tintic, Selma, and the Tintic-Delmar, were being worked when visited by the writer.

LEHI-TINTIC.

The Lehi-Tintic mine is on the west slope of the ridge, nearly due east of Greely Springs, which furnishes a water supply to different properties in its vicinity. The mine formerly produced a good grade of oxidized silver-lead ore from workings near the top of the ridge. The ore is said to have followed a N. 50° E. fissure (in Mississippian (?) limestone), but to have pinched out downward. At the time of the writer's hasty visit (July, 1912) a tunnel was being driven along a strongly undulating fissure zone that strikes generally N. 60° E. and dips 45° NW. to 90°, with the intention of prospecting beneath the old ore body. A few small indications of ore, but none of consequence, were said to have been found along this fissure zone. In March, 1913, it was reported in several mining journals that ore containing lead, silver, and a little gold had been found on the tunnel level.

SELMA.

The Selma property is at the northwest base of Pinyon Peak, a short distance beyond the northern boundary of the Tintic quadrangle. The surface country rock is the Bluebell dolomite, much fissured and cut by a few rhyolite dikes. The principal workings consist of a long tunnel and a shaft 210 feet deep. The tunnel was run to explore the "cave fissure," a large cavernous pipe of low-grade iron ore, with small quantities of lead and precious metals, which is said to be continuous from the surface downward. Other evidences of mineralization along fissures have been uncovered in small prospects, but none have been developed. At the time of visit (July, 1914) the only activity was at the shaft, which was being equipped with new machinery preparatory to running a drift eastward from the shaft bottom to cut certain of the mineralized fissures and to reach the "cave fissure" at greater depth.

TINTIC-DELMAR.

The Tintic-Delmar property is on the east slope of the ridge, northeast of Pinyon Peak and southeast of the Lehi-Tintic workings. When it was visited (July, 1912) a tunnel had been run in a N. 37° E. direction through the Pine Canyon limestone for 450 feet, and two winzes 50 and 25 feet deep had been sunk from it. The 25-foot winze close to the tunnel face was being sunk along the junction of a N. 25° E. fissure with an easterly fissure and had exposed a few small calcite veinlets. No ore was seen. A little network of calcite veinlets was found in silicified limestone about 125 feet from the mouth of the tunnel, and an assay of the silicified rock was said to have yielded encouraging quantities of silver and gold; but no development of this rock had been attempted.

INDEX.

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R.U.Goode, Geographer in charge.
Triangulation by S.S.Gannett.
Topography by W.T.Griswold and R.B.Marshall.
Surveyed in 1896-1897.
Culture revised in 1911 by W.M.Beaman.

GEOLOGIC MAP OF TINTIC MINING DISTRICT, UTAH

Scale $\frac{1}{9,600}$

0 ⅛ ¼ ½ ¾ 1 Mile
0 400 800 1600 2400 3200 4000 Feet
0 100 200 400 600 800 1000 Meters

Contour interval 20 feet.
Datum is mean sea level.
1918

Geology by G. F. Loughlin
Surveyed in 1911

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Recent

Qal — **Alluvium**

CARBONIFEROUS

Upper Mississippian

Ch — **Humbug formation**
(*Dark argillaceous shale and calcareous quartzite*)

Cp — **Pine Canyon limestone**
(*Mostly dark fossiliferous limestone with prominent black chert nodules; coarse-grained pure limestone with upper (?) Mississipian fossils near top*)

Lower Mississippian

Cg — **Gardner dolomite**
(*Largely dark bluish-gray dolomite with beds of nearly black argillaceous limestone. Contains lower Mississippian fossils*)

Cv — **Victoria quartzite**
(*Two or more beds of calcareous quartzite alternating with limestone*)

UNCONFORMITY

ORDOVICIAN

Upper to Lower Ordovician

Ob — **Bluebell dolomite**
(*Alternating beds of light-gray and dark bluish-gray dolomite. Appearance very similar to Cole Canyon dolomite. Contact metamorphic in part*)

Lower Ordovician

Oo — **Opohonga limestone**
(*Striped shaly limestone, weathered surfaces yellow to red alternating with bluish gray, cherty in places, especially lower beds. Resembles parts of Teutonic and Herkimer limestones but is redder on the whole. Contact metamorphic in part*)

Oa, Oed — **Ajax limestone**
(*Dark bluish-gray magnesian limestone, with lighter-gray chert nodules and lenses. Includes, 90 feet above base, Emerald dolomite member,* Oed, *creamy-white fine to medium grained dolomite. Quartzite lenses at base. Contact metamorphic in part*)

UNCONFORMITY

CAMBRIAN

Upper Cambrian ?

€u — **Opex dolomite**
(*Dark-gray dolomite with interbedded shaly limestone and shale and a few thin quartzite lenses. Contact metamorphic in part*)

Middle Cambrian

€mc — **Cole Canyon dolomite**
(*Alternating beds of light-gray and dark bluish-gray dolomite, in appearance very similar to Bluebell dolomite. Contact metamorphic in part*)

€mb — **Bluebird dolomite**
(*Dark bluish-gray dolomite spangled with short white coarser-grained rod-shaped bodies less than half an inch long*)

€mh — **Herkimer limestone**
(*Mottled and banded argillaceous limestone, with yellowish-brown blotches and stripes in a dark-bluish body. Resembles parts of Teutonic and Opohonga limestones*)

€md — **Dagmar limestone**
(*Finely banded argillaceous limestone, nearly white on weathered surface, gray to nearly black on fresh fracture*)

€mt — **Teutonic limestone**
(*Dark-colored, mostly argillaceous limestone, with a few dolomitic beds. A large portion is mottled and striped with yellowish brown, resembling Herkimer limestone and parts of Opohonga limestone. Many of the lower beds are pisolitic*)

€mo — **Ophir formation**
(*Greenish, weathering brownish shale, largely micaceous and with slaty cleavage. Contains beds of dark limestone of same type as in Teutonic limestone. Contact metamorphic in part*)

Lower Cambrian

€l — **Tintic quartzite**
(*Light-colored quartzite, with several thin beds of fine to medium conglomerate. Very pure as a whole, but somewhat calcareous and argillaceous in uppermost beds. May include some pre-Cambrian*)

IGNEOUS ROCKS

TERTIARY (post-Eocene)

Tmd — **Monzonite porphyry dikes**

Tm — **Monzonite**

Tmp or Tbl — **Monzonite porphyry, Tmp and biotite latite, Tbl**
(*Connected with the Sunrise Peak vent. Probably but not certainly of effusive character*)

Tl — **Latite tuff**
(*Silicified and therefore resembling the rhyolite tuff*)

Tsr — **Swansea rhyolite**
(*Intrusive*)

Tpr — **Packard rhyolite**
(*Exposed portions entirely effusive save for some small dikes in upper Jenny Lind Canyon*)

Trt — **Rhyolite tuff**
(*Mostly altered*)

Ter — **Early rhyolite**
(*Characterized by brown color, marked fluidal structure and absence of quartz phenocrysts*)

43° — Strike and dip of beds

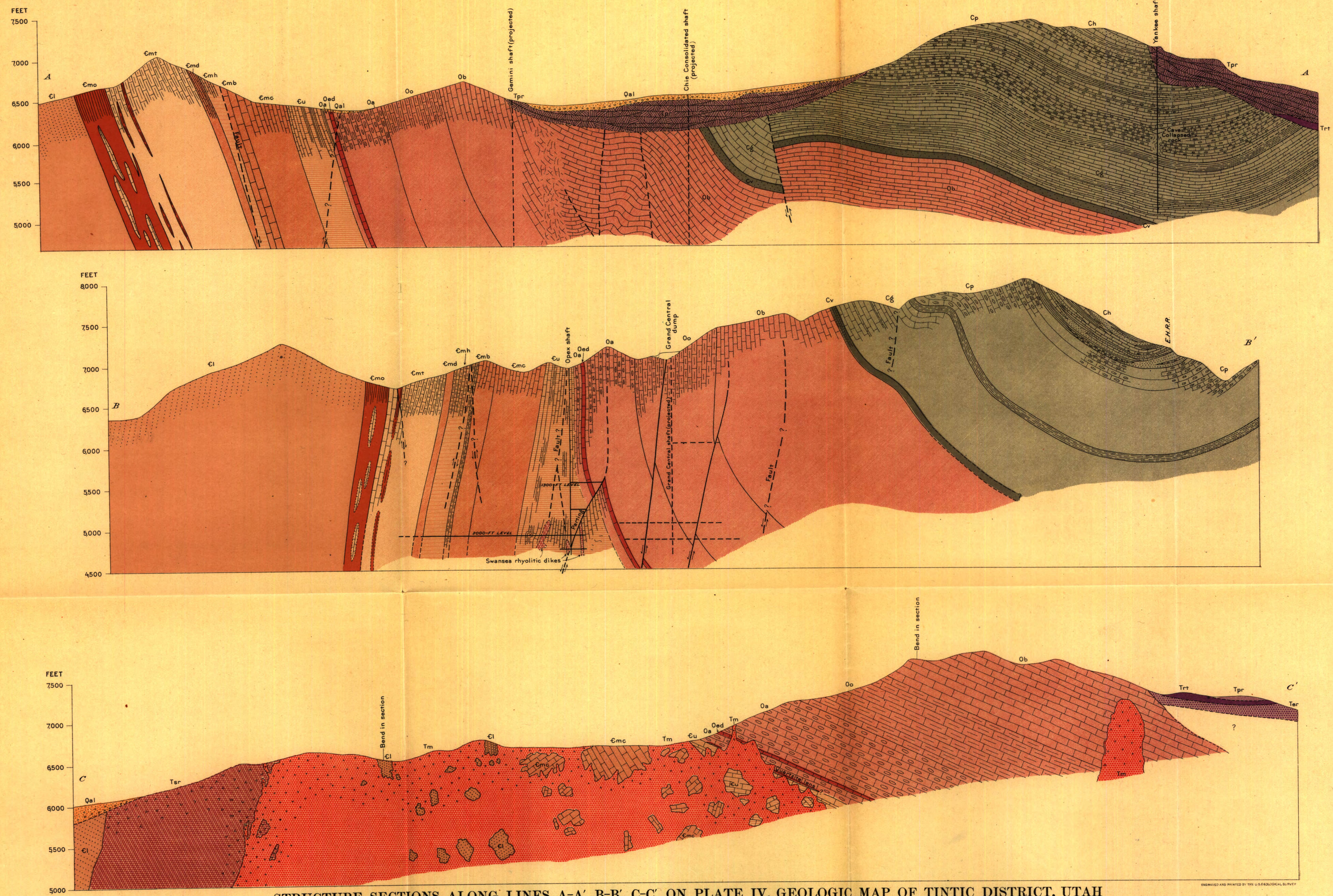
PROPERTY MAP
TINTIC AND NORTH TINTIC
MINING DISTRICTS
UTAH

SCALE

0 1200 2400 3600

1 INCH = 1200 FEET

G. W. CRANE
414 So. 13TH E.
SALT LAKE CITY, UTAH



STRUCTURE SECTIONS ALONG LINES A-A', B-B', C-C', ON PLATE IV, GEOLOGIC MAP OF TINTIC DISTRICT, UTAH

Scale 1/62500

1918

For explanation of colors and letter symbols see legend on geologic map, Plate IV

LEGEND

Veins (outcrops and underground continuation)
(*Dashed lines indicate probable continuation*)

Ore bodies with no outcrop

Ore bodies
Exact position not guaranteed

Red numbers indicate elevation of ore bodies

R.U. Goode, Geographer in charge.
Triangulation by S.S. Gannett.
Topography by W.T. Griswold and R.B. Marshall.
Surveyed in 1896-1897.
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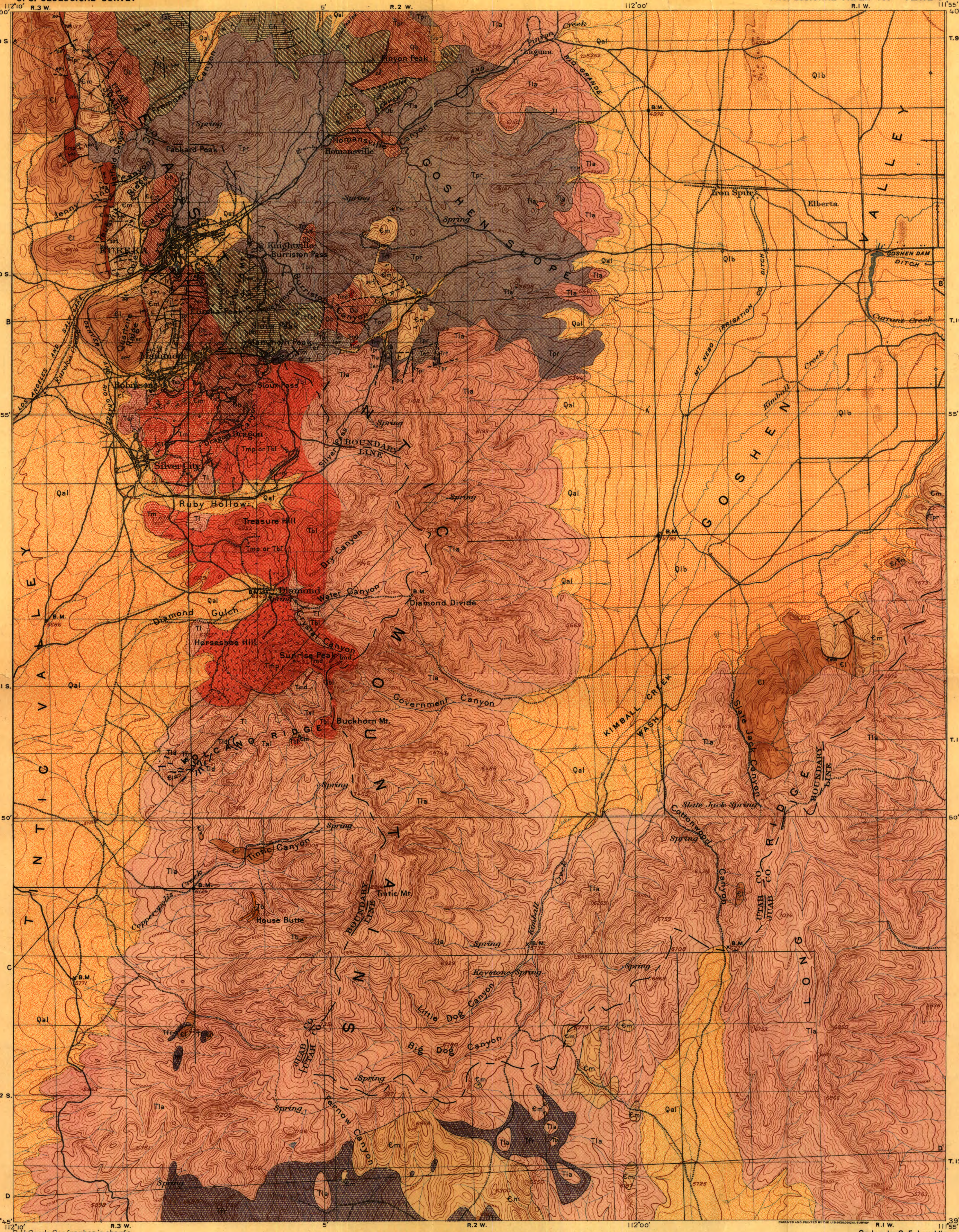
MAP OF THE TINTIC MINING DISTRICT, UTAH, SHOWING PRINCIPAL ORE BODIES

Scale $\frac{1}{9600}$

0 ⅛ ¼ ½ ¾ 1 Mile
0 400 800 1600 2400 3200 4000 Feet
0 100 200 400 600 800 1000 Meters

Contour interval 20 feet.
Datum is mean sea level.
1918



R.U. Goode, Geographer in charge.
Triangulation by S.S. Gannett.
Topography by R.B. Marshall.
Surveyed in 1897.

GEOLOGIC MAP OF TINTIC QUADRANGLE, UTAH

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

Datum is mean sea level.

1918

Geology by G. F. Loughlin
Surveyed in 1911

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Recent

Qal — Alluvium

Pleistocene

Qlb — Lake Bonneville beds

CARBONIFEROUS

Upper Mississippian

Ch — Humbug formation (*Alternating beds of limestone, sandstone, and shale*)

Lower Mississippian

Cp — Pine Canyon limestone, Gardner dolomite, and Victoria quartzite

UNCONFORMITY

DEVONIAN

Upper Devonian ?

Dp — Pinyon Peak limestone

ORDOVICIAN

Upper to Lower Ordovician

Ob — Bluebell dolomite, Opohonga limestone, and Ajax limestone. Contact metamorphic in part

UNCONFORMITY

CAMBRIAN

Upper Cambrian ?

€u — Opex dolomite. Contact metamorphic in part

Middle Cambrian

€m, €mo — Chiefly light and dark-gray dolomite, shaly limestones, and shale, including Cole Canyon dolomite, Bluebird dolomite, Herkimer limestone, Dagmar limestone, Teutonic limestone, and Ophir formation, €mo. Contact metamorphic in part

Lower Cambrian

€l — Tintic quartzite (*May include some pre-Cambrian*)

IGNEOUS ROCKS

TERTIARY (post-Eocene)

Tb — Basalt dikes

Tm — Monzonite

Tld, Tmd — Latite (Tld) and monzonite porphyry (Tmd) dikes

Tmp, Tbl — Monzonite porphyry, Tmp and associated biotite latite, Tbl

Tal — Augite latite

Tl — Latite tuff and breccia

Tla — Latite (and andesite ?) (*Flows, tuffs, and breccias not subdivided*)

Tsr — Swansea rhyolite

Tpr — Packard rhyolite

Tfr — Fernow rhyolite

Trt — Rhyolite tuff

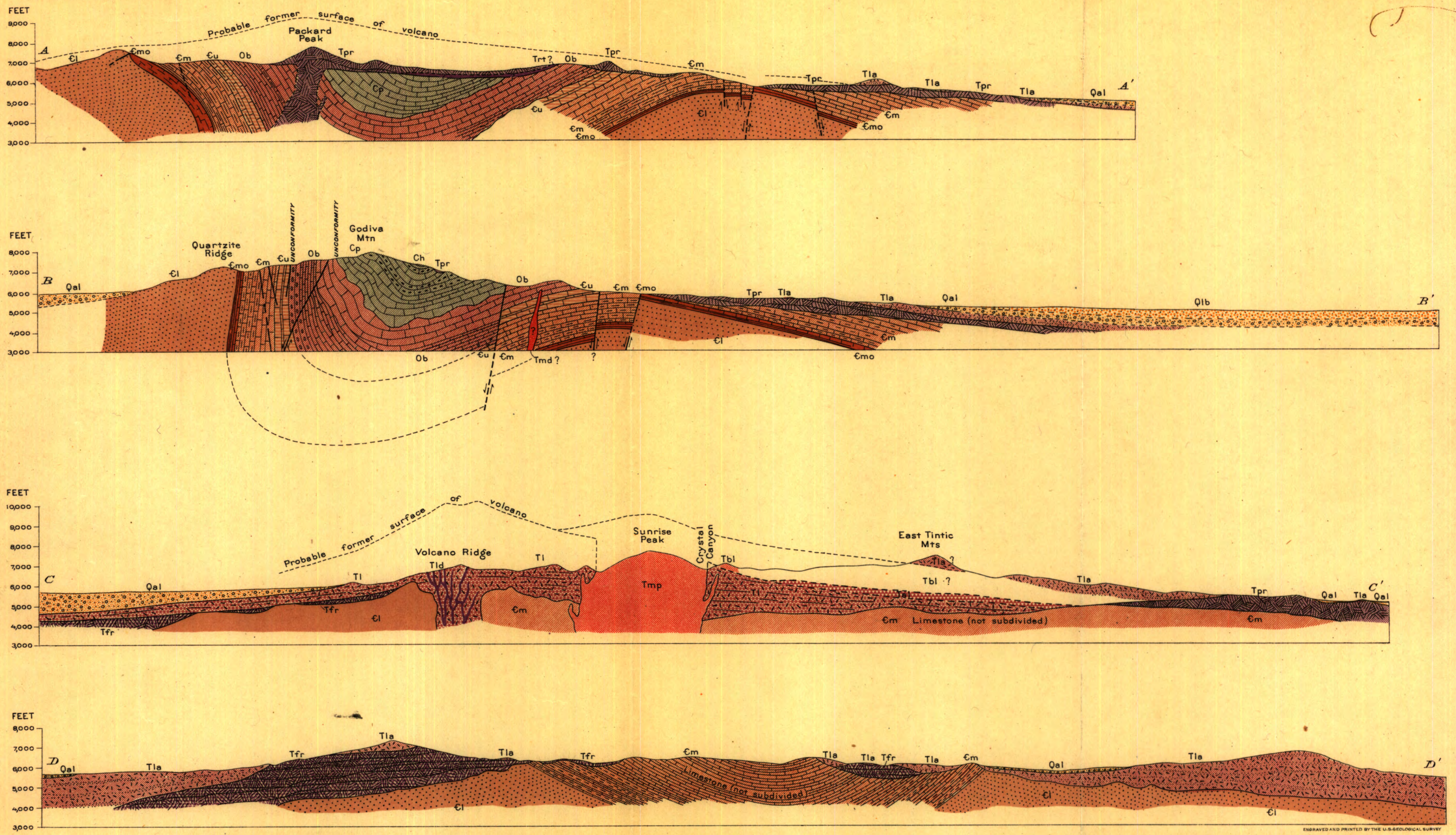
Ter — Early rhyolite

20 — Strike and dip of beds

20 — Strike of vertical bed

Fault

Anticline



STRUCTURE SECTIONS ALONG LINES A-A′, B-B′, C-C′, D-D′, ON PLATE I, GEOLOGIC MAP OF TINTIC QUADRANGLE, UTAH

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 3 4 Miles

1918

For explanation of colors and letter symbols see legend on geologic map, Plate I

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Recent

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CARBONIFEROUS

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(*Dark argillaceous shale and calcareous quartzite*)

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IGNEOUS ROCKS

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(*Mostly altered*)

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(*Characterized by brown color, marked fluidal structure and absence of quartz phenocrysts*)

Strike and dip of beds

R.U.Goode, Geographer in charge.
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Topography by W.T.Griswold and R.B.Marshall.
Surveyed in 1896-1897.
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GEOLOGIC MAP OF TINTIC MINING DISTRICT, UTAH

Scale $\frac{1}{9600}$

0 — $\frac{1}{8}$ — $\frac{1}{4}$ — $\frac{1}{2}$ — $\frac{3}{4}$ — 1 Mile

0 — 400 — 800 — 1600 — 2400 — 3200 — 4000 Feet

0 — 100 — 200 — 400 — 600 — 800 — 1000 Meters

Contour interval 20 feet.
Datum is mean sea level.
1918

Geology by G. F. Loughlin
Surveyed in 1911

PROPERTY MAP
TINTIC AND NORTH TINTIC
MINING DISTRICTS
UTAH

SCALE

0 1200 2400 3600'

1 INCH = 1200 FEET

G. W. CRANE
414 So. 13th E.
SALT LAKE CITY-UTAH

COMPLIMENTS OF

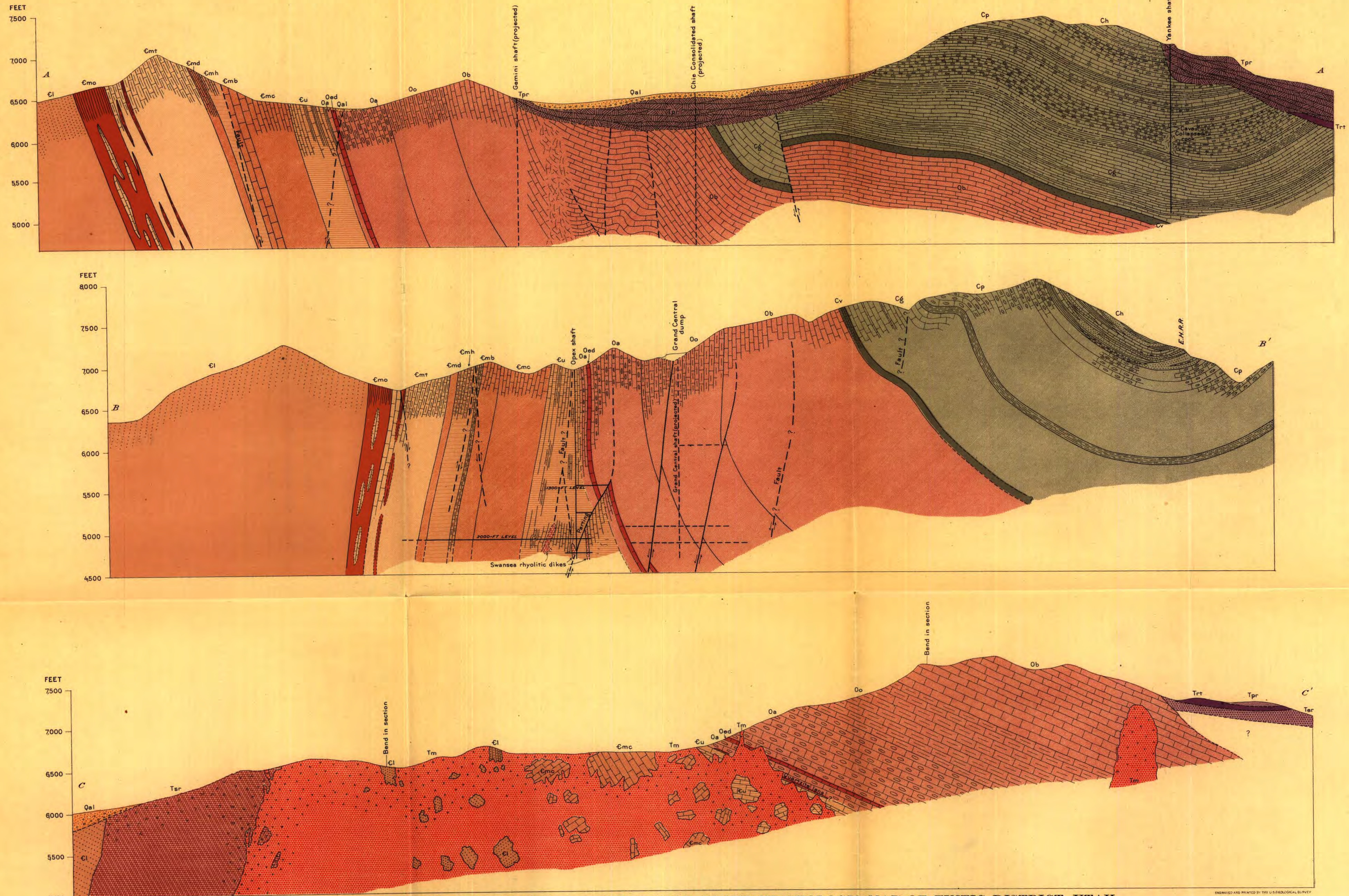
URE, PETT & MORRIS

STOCKS • COMMODITIES • BONDS

MEMBERS
Chicago Board of Trade
Salt Lake Stock Exchange
Chicago Mercantile Exchange

SALT LAKE CITY, UTAH IDAHO FALLS, IDAHO

LONGITUDINAL SECTION ALONG THE FOURTH ORE ZONE FROM BECK TUNNEL TO IRON BLOSSOM No. 1



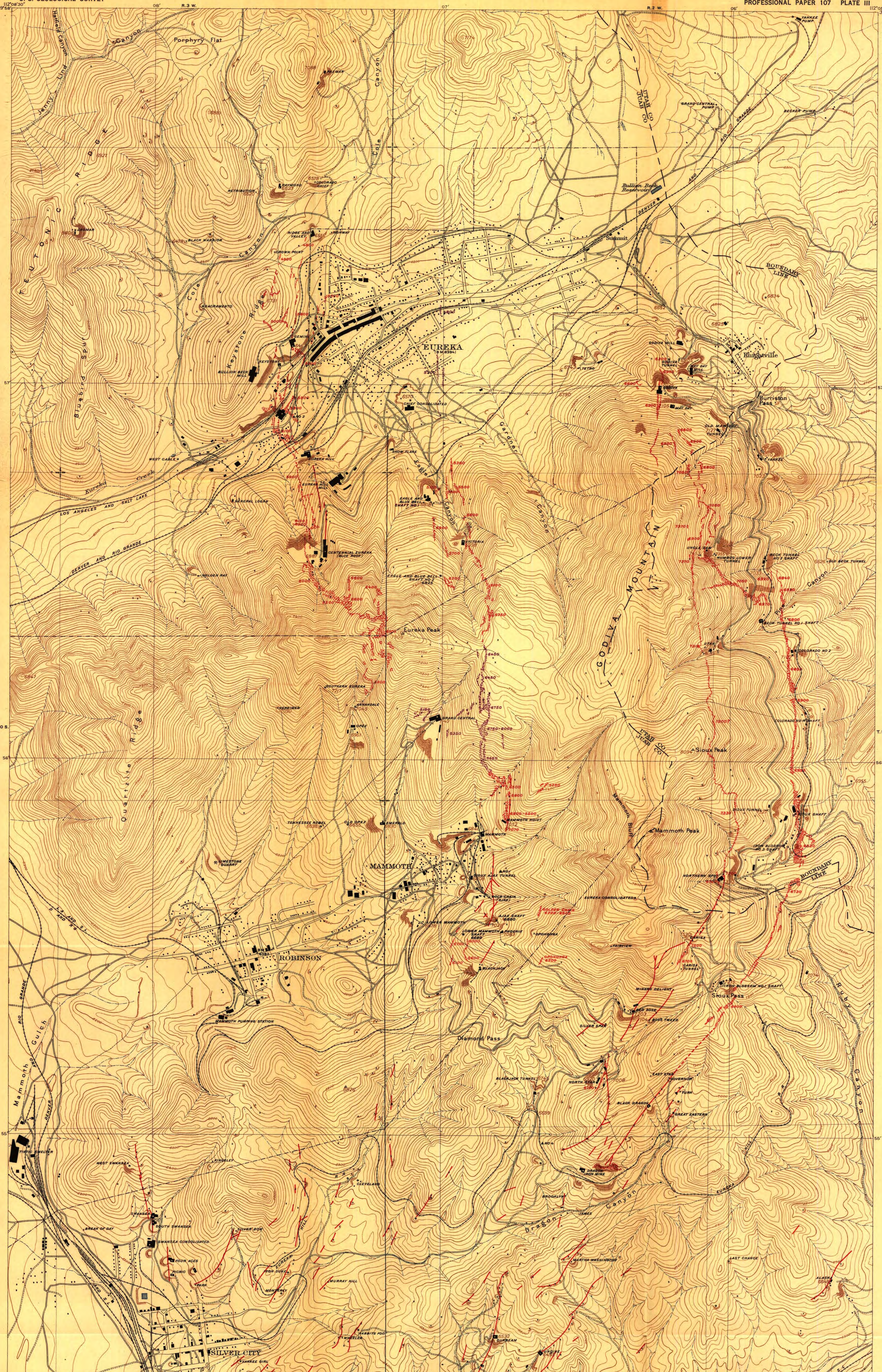
STRUCTURE SECTIONS ALONG LINES A-A', B-B', C-C', ON PLATE IV, GEOLOGIC MAP OF TINTIC DISTRICT, UTAH

Scale $\frac{1}{48000}$

0 1 Mile

1918

For explanation of colors and letter symbols see legend on geologic map, Plate IV



LEGEND

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(*Dashed lines indicate probable continuation*)

Ore bodies with no outcrop

Ore bodies
Exact position not guaranteed

Red numbers indicate elevation of ore bodies

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MAP OF THE TINTIC MINING DISTRICT, UTAH, SHOWING PRINCIPAL ORE BODIES

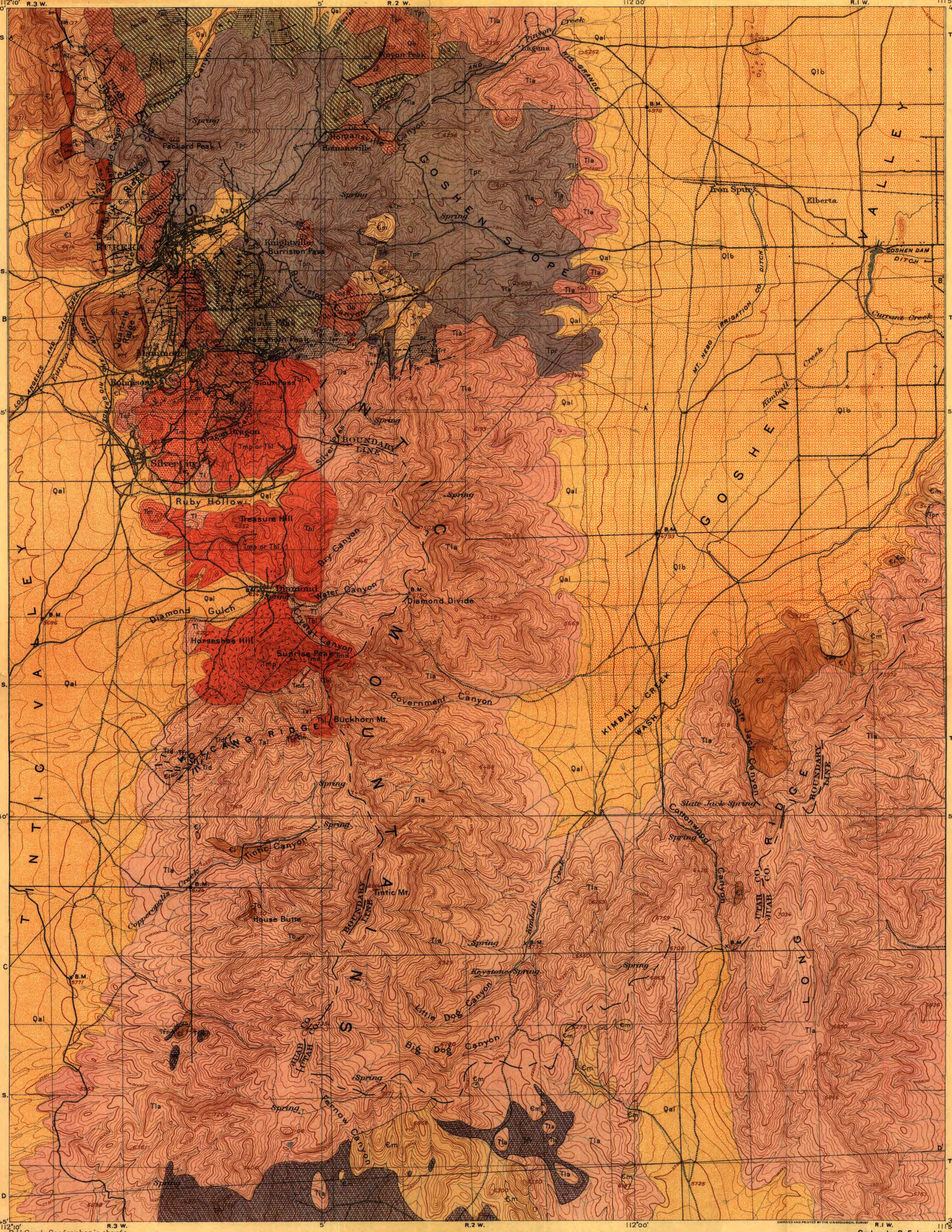
Scale $\frac{1}{9600}$

0 1/8 1/4 1/2 3/4 1 Mile

0 400 800 1600 2400 3200 4000 Feet

0 100 200 400 600 800 1000 Meters

Contour interval 20 feet.
Datum is mean sea level.
1918



LEGEND

SEDIMENTARY ROCKS

QUATERNARY
- Recent — Qal — Alluvium
- Pleistocene — Qlb — Lake Bonneville beds

CARBONIFEROUS
- Upper Mississippian — Ch — Humbug formation *(Alternating beds of limestone, sandstone, and shale)*
- Lower Mississippian — Cp — Pine Canyon limestone, Gardner dolomite, and Victoria quartzite

UNCONFORMITY

DEVONIAN
- Upper Devonian ? — Dp — Pinyon Peak limestone

ORDOVICIAN
- Upper to Lower Ordovician — Ob — Bluebell dolomite, Opohonga limestone, and Ajax limestone. Contact metamorphic in part

UNCONFORMITY

CAMBRIAN
- Upper Cambrian ? — Ꞓu — Opex dolomite. Contact metamorphic in part
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- Lower Cambrian — Ꞓt — Tintic quartzite *(May include some pre-Cambrian)*

IGNEOUS ROCKS

TERTIARY (post-Eocene)
- Tb — Basalt dikes
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- Tld, Tmd — Latite (Tld) and monzonite porphyry (Tmd) dikes
- Tmp, Tbl — Monzonite porphyry, Tmp and associated biotite latite, Tbl
- Tal — Augite latite
- Tl — Latite tuff and breccia
- Tla — Latite (and andesite ?) *(Flows, tuffs, and breccias not subdivided)*
- Tsr — Swansea rhyolite
- Tpr — Packard rhyolite
- Tfr — Fernow rhyolite
- Trt — Rhyolite tuff
- Ter — Early rhyolite

Strike and dip of beds

Strike of vertical bed

Fault

Anticline

GEOLOGIC MAP OF TINTIC QUADRANGLE, UTAH

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

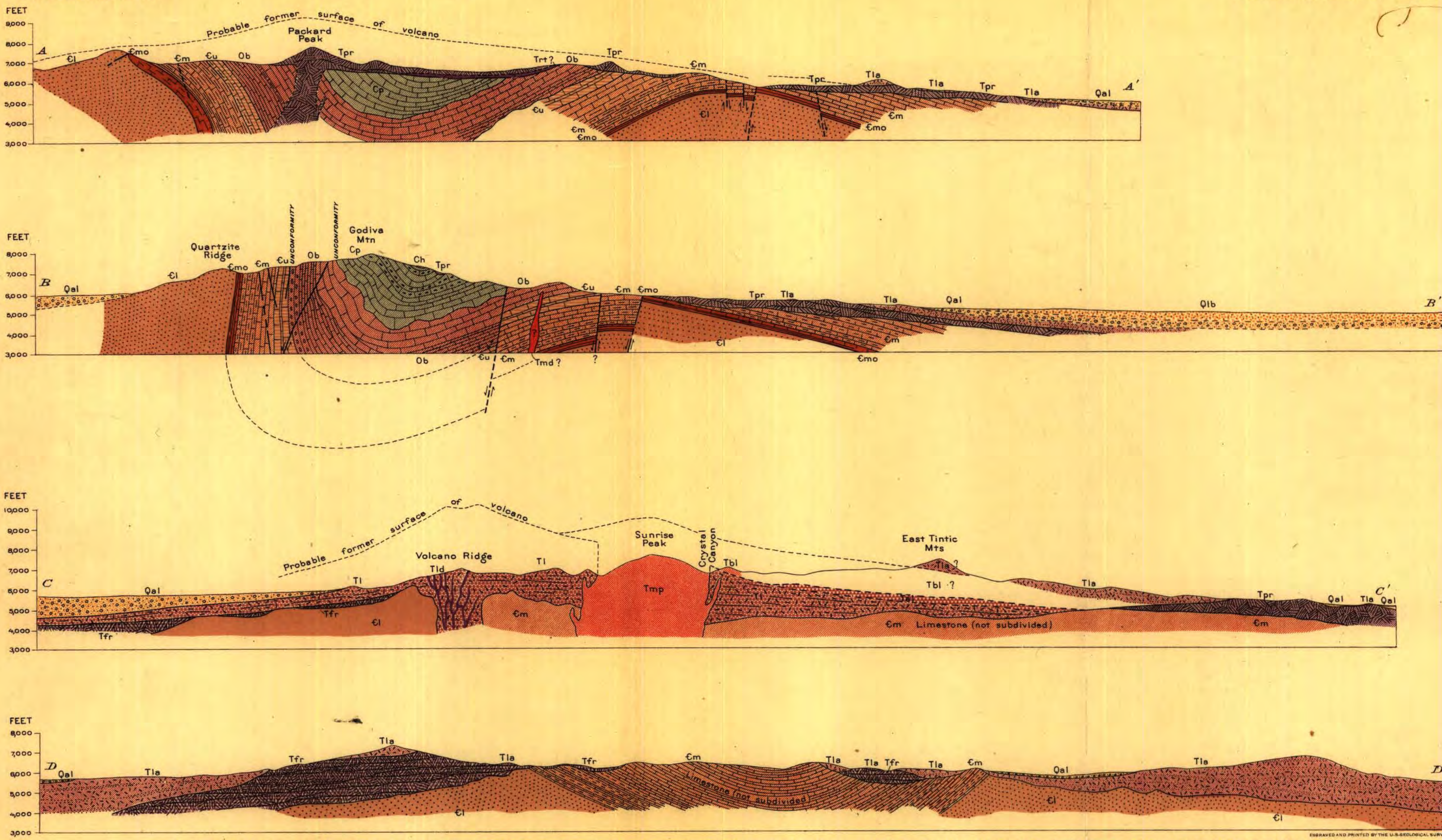
Contour interval 50 feet.

Datum is mean sea level.

1918

R.U. Goode, Geographer in charge.
Triangulation by S.S. Gannett.
Topography by R.B. Marshall.
Surveyed in 1897.

Geology by G. F. Loughlin
Surveyed in 1911



STRUCTURE SECTIONS ALONG LINES A–A′, B–B′, C–C′, D–D′, ON PLATE I, GEOLOGIC MAP OF TINTIC QUADRANGLE, UTAH

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1918

For explanation of colors and letter symbols see legend on geologic map, Plate I

PLAN OF ORE BODIES ALONG THE FOURTH ORE ZONE FROM BECK TUNNEL TO IRON BLOSSOM No. 1